

DER-CAM User Manual

Full DER Web Optimization Service:
a project partly financed by
the U.S. Department of Energy

DER-CAM Version 4.4.1.4

Interface Version (GUI) 1.5.0

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I. Introduction to DER-CAM Web Optimization

This document contains the user manual for accessing DER-CAM using the Web Optimization Interface in its current version, 4.1.4.4, and gives examples of its functionalities and options.

1. What is DER-CAM?

DER-CAM (Distributed Energy Resources Customer Adoption Model) is a decision support tool for investment and planning of distributed energy resources (DER) in buildings and microgrids. The problem addressed by DER-CAM is formulated as a mixed integer linear program (MILP) that finds optimal DER investments while minimizing total energy costs, carbon dioxide (CO₂) emissions, or both criteria simultaneously through a multi-objective approach.

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the main grid and operate both in grid-connected or island-mode. Distributed Energy Resources are commonly defined as a set of locally available technologies and strategies with potential to make energy use more efficient, accessible, and environmentally sustainable. These solutions include power generation and combined heat and power (CHP) using conventional fuel-fired technologies, but also renewable technologies such as PV, and energy management strategies such as demand response, load shifting, and peak-shaving. Storage technologies, including stationary storage, mobile storage in the form of electric vehicle batteries, as well as thermal storage tanks, are also considered DER.

To optimize DER investments DER-CAM chooses the portfolio of technologies that minimizes costs and/or environmental burdens, based on optimized hourly dispatch decisions that consider specific site load, price information, and performance data for available equipment options. The output results are simultaneously comprised of the optimal technology portfolio and the corresponding dispatch that justifies the investment.

1.1. Key inputs of the model

a. Customer's end-use hourly load profiles – typically for space heat, hot water, natural gas only, (electric) cooling, (electric) refrigeration, and electricity only – defined over three day-types: week days, weekend days, and peak/outlier days.

b. Customer's default electricity tariff, natural gas prices, and other relevant utility price data.

c. Capital costs, operation and maintenance (O&M) costs, and fuel costs associated with the various available technologies, as well as the discount rate on customer investment and maximum allowed payback.

d. Basic technical performance indicators of generation and storage technologies including the thermal-electric ratio that determines the amount of residual heat that is available as a function of generator electric output.

1.2. Outputs determined by DER-CAM

a. Optimal capacity of on-site DER.

b. Optimized strategic dispatch of all DER, taking into account energy management procedures.

c. Detailed economic results, including costs of energy supply and all DER related costs.

2. DER-CAM Web Optimization

DER-CAM Web Optimization refers to the service that integrates the DER-CAM model with a web-based user interface. This online platform facilitates the handling of input data and optimization parameters prior to running the algorithm on a dedicated server hosted at LBNL. It also enables graphical visualization of the results and exporting them via e-mail. To simplify, the DER-CAM Web Optimization will simply be referred to as DER-CAM throughout this document.

II. Getting started with DER-CAM in 5 Steps

In this section we will go through the very first steps to quickly setup a DER-CAM mode.

1. Login

Go to <https://microgrids2.lbl.gov> and enter your user credentials. Click on “Login” and on the following page click on “Full DER-CAM Optimization Service”.


2. Review the Conditions

After the connection to the interface is established, a user agreement will appear. Please review the conditions and click “Accept” to proceed or “Deny” to reject and exit the application.

Note: At this point only advanced DER-CAM users are given a private storage folder for their DER-CAM projects and customized versions. This can be accessed via the “Advanced user Login” button. For standard DER-CAM access all files are currently kept in a common user folder and only the main stable version of DER-CAM is offered.

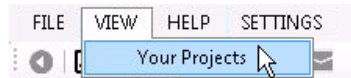
3. Create and Open Projects

3.1. New Project

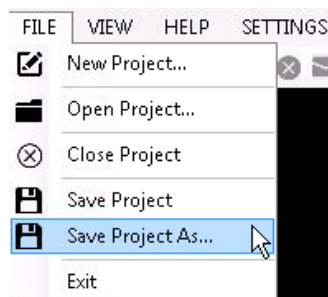
On the main window (Figure 1) click on “New Project...” under “Start” to create a new DER-CAM project. Alternatively you may click the  button on the toolbar or select “New Project” from the FILE menu.

3.2. Open an Existing Project

To open an existing project click on “Open Project...” under “Start”, use the button or select “Open Project” from the FILE menu. To view and manage all your projects (rename, delete), click on the VIEW menu and select “Your Projects”.



TIP: To create quickly a new project from an existing one, select “Save Project As...” in the File menu and enter a name for your new project.



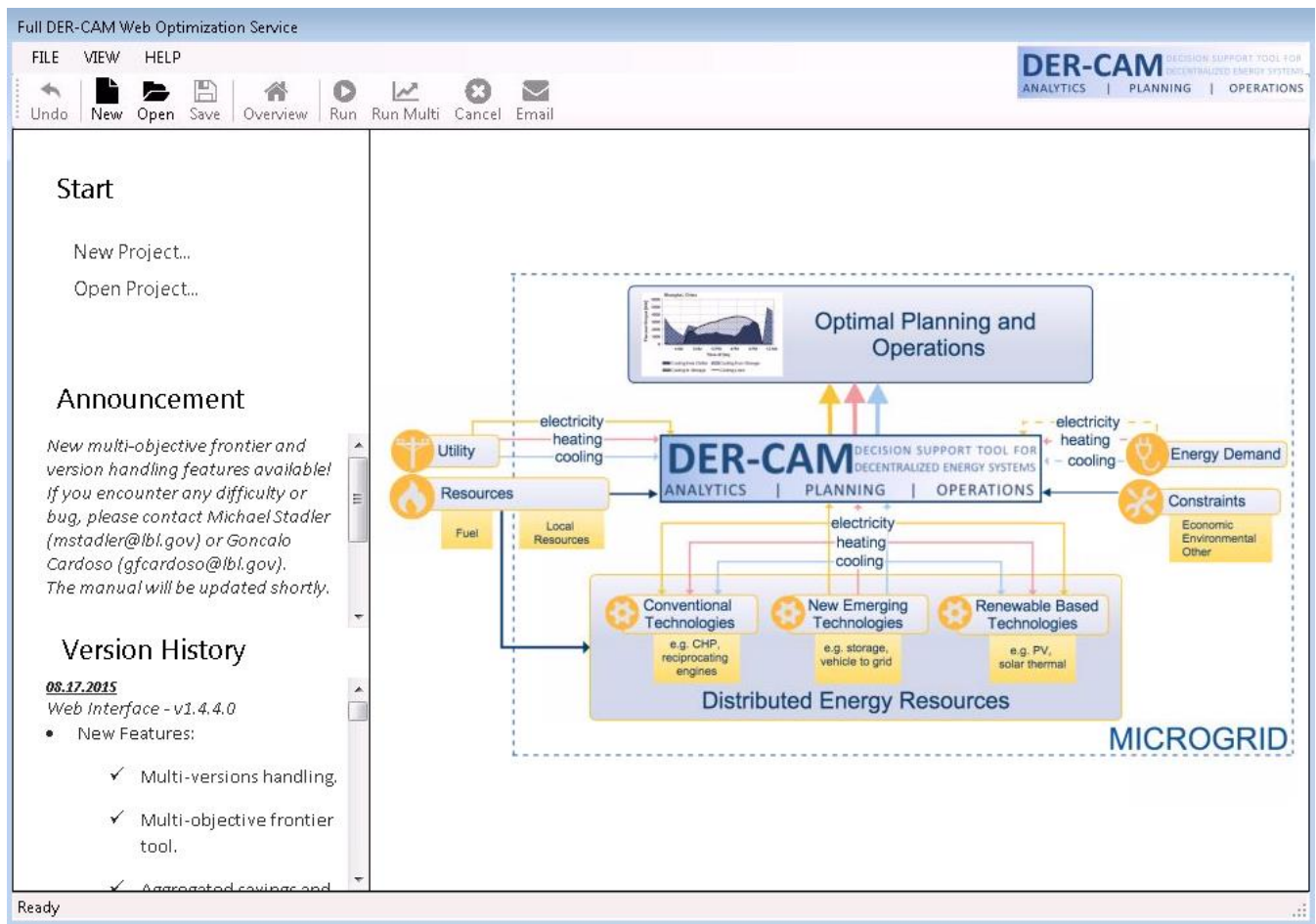


Figure 1: Start Window

4. Define Project Settings

4.1. Project name and DER-CAM versions

After selecting “New Project” the New Project window will appear (see Figure 2). Enter a project name and select the DER-CAM version among the four options available: Basic, Intermediate, Advanced and Full User.

A summary of the main input and output functionalities available in each version of the DER-CAM is presented in the Table 1.

A full description of each version can be found in Annex A.

<div> <div>Enabled</div> <div>Disabled</div> </div>		DER-CAM Versions			
Functionalities		Basic	Intermediate	Advanced	Full User
Inputs	Scanning Databases	Enabled	Enabled	Enabled	Enabled
	Editable Inputs (Loads, Solar Radiation, Tariffs)	Disabled	Enabled	Enabled	Enabled
	Microgrid outages (forced islanding)	Disabled	Enabled	Enabled	Enabled
	Fee-in tariffs	Disabled	Enabled	Enabled	Enabled
	Basic Load Management and Resiliency Features	Disabled	Enabled	Enabled	Enabled
	Advanced Load Management (Load Shifting + Demand Response)	Disabled	Disabled	Enabled	Enabled
	Full Customization of the microgrid	Disabled	Disabled	Enabled	Enabled
	Building Retrofit Settings	Disabled	Disabled	Disabled	Enabled
	Financial Settings	Disabled	Disabled	Disabled	Enabled
	Zero Net Energy Constraint	Disabled	Disabled	Disabled	Enabled
Outputs	Run Base Case	Enabled	Enabled	Enabled	Enabled
	Investment Analysis	Enabled	Enabled	Enabled	Enabled
	Tradeoff analysis (outage costs vs load curtailment/investments in DER)	Disabled	Enabled	Enabled	Enabled
	Power Exports Scenarios	Disabled	Enabled	Enabled	Enabled
	Islanding Scenarios	Disabled	Enabled	Enabled	Enabled
	Results for real test sites (full customizable microgrid)	Disabled	Disabled	Enabled	Enabled
	Building Shell improvements	Disabled	Disabled	Disabled	Enabled
	Performance and investment subsidies	Disabled	Disabled	Disabled	Enabled
	Net Metering and Zero Net Energy	Disabled	Disabled	Disabled	Enabled

Table 1: Overview of DER-CAM versions.

Figure 2: New Project Window

4.2. Add DER-CAM databases

DER-CAM provides three types of databases in order to illustrate the main inputs required by the tool and help building new cases and microgrid scenarios: Load Data; Solar Data and Tariff Data. This information corresponds to real data obtained for specific locations that is made available in the “New Project” window. As shown in Table 1, some versions of the DER-CAM allow the user to modify these pre-defined values while building the case. Each databased can be enabled by ticking the corresponding checkbox.

a. Load Database:

In order to get a load profile from the database, information about the location (Country, State, and City), the type of building, and the period of construction are required. Once this is provided and the data is loaded, you may browse through it by clicking on each of the available tabs: “Electricity Only”, “Cooling”, “Refrigeration”, “Space Heating”, “Water Heating”, “Natural Gas Only”. This navigation buttons show you the disaggregated

information by the type of energy use. The slider on the right allows you to change the type profile being displayed. Three types of daily profiles are considered: the “Week” profile, comprising the average hourly consumption of the weekdays; the “Weekend” profile, containing the average hourly consumption of the weekend day; the “Peak” profile that is built considering the highest values registered for the hourly consumption in each location.

These load profiles represent different consumption behaviors and are built assuming an annual energy consumption of 1GWh. The magnitude of the profile can be scaled by using the “Multiplier” boxes, located bellow the load data fields, where you can set the total annual consumption of your installation.

More information about the Load Database is provided by clicking on the “Information on load data” button. This will load the pop-up window shown in Figure 3, providing more details about the assumptions and locations regarding the database.

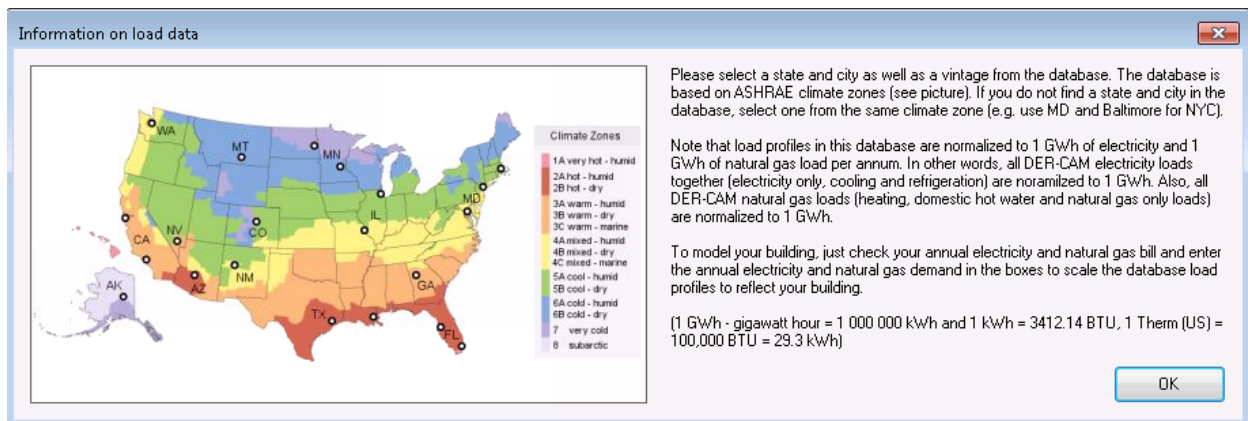


Figure 3: Information on Load Data window

b. Solar Database:

Solar database provides irradiance values (in kW/square meter) for specific locations. These are average values from the Typical Meteorological Year (TMY) collation. Besides the location data (State and City) the user is required to select the TMY edition from which the irradiance values should be extracted.

More information about the TMY editions are presented in a specific help widow (Figure 4) that can be opened by clicking on “Information on solar data” button.

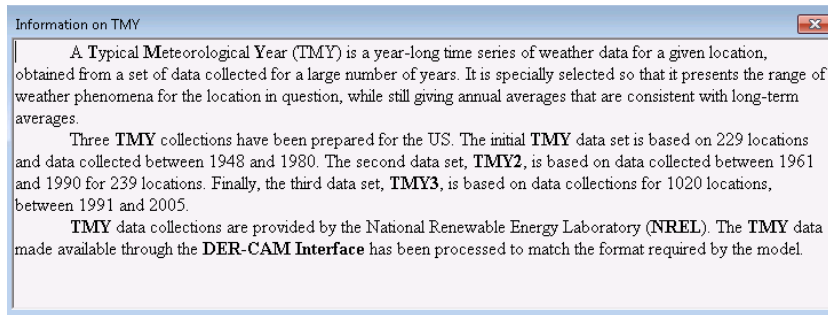


Figure 4: Information on Solar Data window

c. Tariff Database:

The tariffs available in DER-CAM database consist of a collection of data for all locations found in the DER-CAM Loads Database. In this database preparation, one utility was selected in each location and three tariff rates were made available in different datasets (Small, Medium and Large/Industrial) to accommodate buildings with different peak loads. Thus, besides the information about the location (State and City), the user must also select the most adequate dataset. More information about the three levels of tariff rates in each location (Figure 5) can be obtained by clicking in “Information on Tariff Data”.

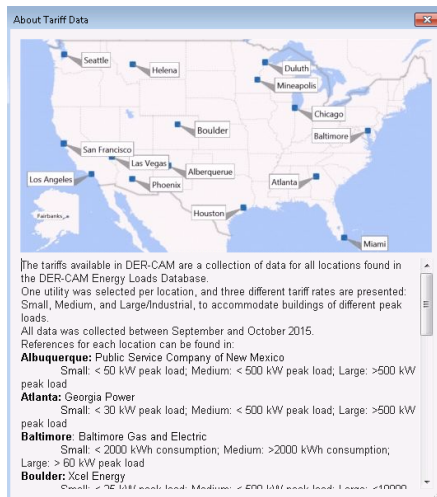
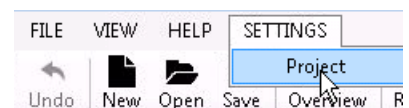


Figure 5: Information on Tariff data

4.3. View and modify project settings

Viewing and modifying the project settings can be done at any point during the session by clicking on the “SETTINGS” menu.



5. Main screen overview

After creating a new project, you will be presented with the main screen. As shown in Figure 6, this main panel is divided in three areas: Parameters Menu, Tables Input Area, and Help Area. The Parameters Menu enables a hierarchical navigation through the parameters required by DER-CAM. By selecting each category of inputs, the corresponding input table will appear in the Table Area. Help information about the parameters will be presented in the Help Area, on the right side of the panel.

By clicking on the small arrow in the top of the screen, the Actions Menu will slide down from the top bar. This menu comprises basic functionalities, such as screen refreshing and snapshot taking. Finally, at the bottom of the screen, the information regarding the DER-CAM version being used is displayed.

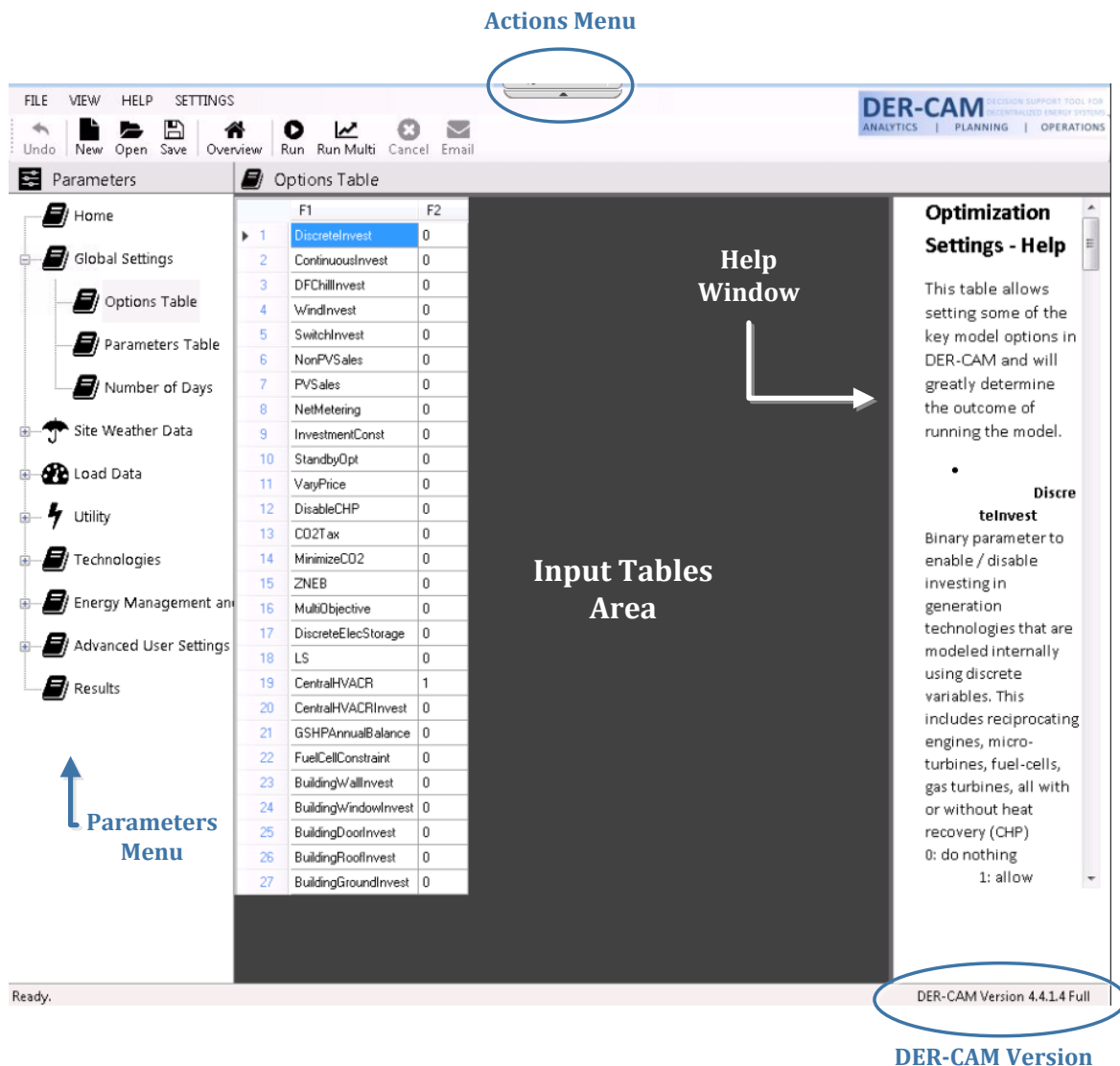


Figure 6: Input Main Screen

III. Overview of input parameters

1. Global Settings

The Global Settings menu contains the general optimization parameters that will define the nature of the run taking place. It also includes the main financial and technical parameters, as well as the high level options associated with the technologies to be considered in the optimization. Three subsections are included within Global Settings: Options Table; Parameter Table; Number of Days.

1.1. Options Table

The Options Table is a table used to define key aspects in each model. It consists of a set of binary parameters, where 0 disables and 1 enables the action controlled by that parameter. For instance, setting “DiscreteInvest” to 1 will enable the possibility of investing in discrete technologies, which consist of conventional distributed generation technologies modeled internally using discrete variables. This includes reciprocating engines, microturbines, fuel-cells, or gas turbines, as opposed to “continuous technologies”, whose capacity is modeled using continuous variables. This is an important distinction, as “Discrete technologies” can only be installed in discrete quantities of the nameplate capacity. In contrast, the optimal capacity of “Continuous technologies”, can be any continuous non-negative number. This distinction is justified by the commercial available sizes of technologies and their economies of scale.

Likewise, if the “NonPVSales” parameter is set to 1, DER-CAM will consider exports in the optimization process using prices found in the “PX Price” table under “Advanced User Settings”. Setting this parameter to 1 will only enable sales of conventional DG technologies, since the PV sales are controlled by a specific “PVSales” parameter.

Another key element that is defined in this table is the objective function. By default, DER-CAM will minimize the economic function. However, by setting “MinimizeCO2” to 1 the objective will change to CO₂ minimization and by setting “MultiObjective” to 1 a weighted objective of both costs and CO₂ aspects will be considered.

1.2. Parameter Table

In the Parameter Table several project related global values can be set, including the key financial parameters such as the project discount rate, the maximum payback period, and

the reference costs (base case cost) for investment scenarios. The reference costs represent total annual energy costs prior to new investments in distributed generation technologies and can be obtained by running DER-CAM only with the existing on-site technologies (if any). It should be noted that even in the reference case DER-CAM will optimize the dispatch of any existing DER, and, therefore, the reference case may already suggest relevant improvements. The possibility of enabling existing technologies will be discussed in the Technology section.

It is important to take into account that the “BaseCaseCost” is a key input of DER-CAM, since it strongly relates to the maximum payback and, hence, it will affect the technology portfolio that can be included in the optimal solution. The maximum payback constrain is active in every investment run that is performed, and forces that any new investments generate savings against the reference cost that respect a simple payback period shorter than the maximum allowed payback time. In order to obtain a relevant estimation of environmental performance, the CO₂ emissions of the base case should also be introduced in this table.

Furthermore, it should be noted that the maximum payback constrain is still active when CO₂ minimization is selected. For this reason, it may be necessary to either increase the maximum payback period or increase the reference costs when looking for environmental friendly solutions. This is not absolutely necessary, but failing to do so may lead to solutions that have limited potential to reduce emissions.

If “MultiObjective” is being selected as the objective of the optimization, the solution found by DER-CAM will lay between the cost optimal and CO₂ optimal solutions, and the preference over one objective or the other is determined by weighting factors “MultiObjectiveWCosts” and “MultiObjectiveWCO₂”. However, as both these objectives are defined with different units, scaling factors must also be used.

To set the appropriate scaling factors, two separate optimization runs must be performed: the scaling factor for costs, “MultiObjectiveMaxCosts”, is determined by performing a CO₂ minimization and saving the correspondent cost. Similarly, the weighting factor for CO₂, “MultiObjectiveMaxCO₂”, can be found by performing a cost minimization run and saving the corresponding CO₂ emissions. Although this is the recommended approach when using weighted objectives, it should be noted that other procedures are possible and will naturally impact the results. The weighted objective function used by DER-CAM is:

$$\min f = \text{MultiObjectiveWCost} * \left(\frac{\text{TotalAnnual Cost}}{\text{MultiObjectiveMax Cost}} \right) + \text{MultiObjectiveWCO}_2 * \left(\frac{\text{TotalAnnual CO}_2}{\text{MultiObjectiveMax CO}_2} \right)$$

An alternative method to explicitly take CO₂ emissions into account in the optimization process is through the 'CO₂tax' value found in the Parameter Table and enabled through the Options Table. This will introduce a price for the CO₂ emissions in the costs objective function of the DER-CAM.

In summary, performing investment runs in DER-CAM requires a reference case. If the DER-CAM optimization is used with a single objective, a base case scenario with no investments must be run in order to obtain the 'BaseCaseCost' and 'BaseCaseCO₂'. Please note that for this run you must specify the existing technologies without allowing any further investments. In case of using the multi-objective formulation, two additional runs are needed to determine 'MultiObjectiveMaxCosts' and 'MultiObjectiveCO₂'. In chapter IV of this Manual, a Case Study is conducted in order to illustrate the different uses of the DER-CAM.

1.3. Number of Days

The “Number of Days” table shows how the set of days in a year is split between months. Possible day types include week-days, weekend-days and peak-days, as well as the emergency equivalents when considering outages. A more detailed description about emergency days is given in the ‘Resiliency and Demand Management Section’. Please note that the total number of days in this table must equal the number of days in a year, i.e., when defining emergency days the equivalent number must be subtracted from the corresponding non-emergency day type.

2. **Site Weather Data**

The Site Weather Settings menu comprises four tables: Solar Insolation, Ambient Hourly Temperature, Other Location Data, and Wind Power Potential.

2.1. Solar Insolation

Solar Insolation is used as an input to calculate the power generation by photovoltaic panels. Figure 7 shows an example of solar insolation profiles. These default profiles are location dependent and obtained by averaging historical data. It is assumed that one daily profile with hourly time steps represents the daily solar profile for the entire month. If the

DER-CAM solar database has been used, this table will be completed automatically when the model is created.

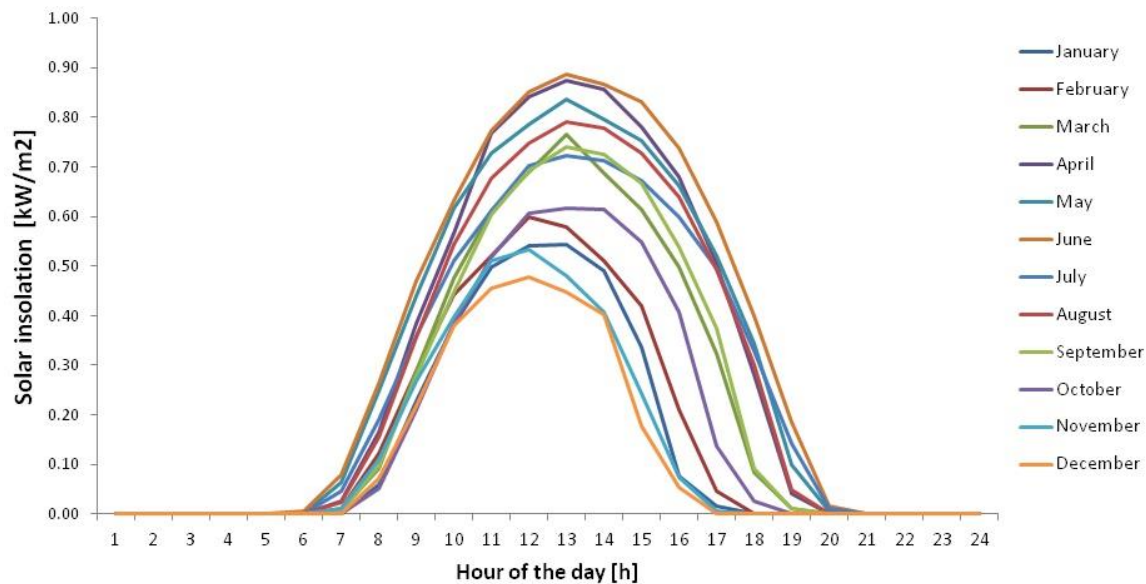


Figure 7: An example of solar insolation data

2.2. Ambient Hourly Temperature

The “Ambient Hourly Temperature” table defines the average hourly ambient dry-bulb temperature over each month. This information is used to estimate losses and efficiency of thermal devices, such as heat storage, but it also affects the efficiency of the photovoltaic and solar thermal panels.

2.3. Other Location Data

The “Other Location Data” table contains the average annual wind speed, defined in m/s. These values have an impact on the efficiency of the photovoltaic and solar thermal panels. It should be noted that this parameter is not associated with wind power.

2.4. Wind Power Potential

The “Wind Power Potential” parameter defines the maximum theoretical power output of one wind turbine, and it is expressed in kWh/h/unit. These values can be obtained by processing historical wind data measurements and computing the theoretical power

output using the turbine power curves in any desired time step and later aggregating those results to an hourly average profile per month. This approach is currently used to minimize errors that would otherwise be introduced by the time granularity used in DER-CAM.

3. Load Data

3.1. Load

In the Load Data menu all load profiles can be found in a single table: Load. Up to six types of end-use consumption profiles can be defined: electricity-only, (electric) cooling, (electric) refrigeration, space heating, water heating, and natural-gas-only loads (*e.g.*, Cooking).

It must be noted that loads are defined as being primarily served by two energy carriers: electricity (that includes electricity-only, cooling, and refrigeration categories) and natural gas loads (that includes natural-gas-only, space-heating, and water-heating).

This distinction is made so that electricity-only loads can be served directly by electricity carrier, whereas electric cooling and electric refrigeration loads may be offset by different energy carriers, as would be the case of heat used to drive an absorption chiller.

Similarly, natural-gas-only loads can only be served directly by natural gas, whereas space-heating and water-heating loads may eventually be served by other heat sources, such as heat recovered from CHP units, heat collected from solar thermal panels, heat collected from heat pumps, or heat collected from boilers using fuels other than natural gas.

Both cooling and refrigeration loads are expressed by the electricity needed to drive an electric chiller of a user-defined COP, found under the Central HVACR technology definitions. Particularly, for a central chiller with a (default value) 4.5 COP, a cooling load of 1 kWh represents the electricity needed to extract 4.5 kWh of heat from the building / microgrid.

All loads must follow the standard DER-CAM format, which allows the definition of hourly load profiles for week, weekend, and peak/outlier day-types per month.

4. Utility

4.1. Global Settings

a. Marginal CO₂ emissions: corresponds to the CO₂ emissions added to the total grid emissions when supplying 1 additional kWh of electricity. They are defined in metric tons of CO₂/MWh (or kg of CO₂ per kWh). It is assumed that local DER will offset CO₂ emissions by this factor, while introducing their own CO₂ emissions. The net balance is used to compute total building/microgrid CO₂ emissions.

b. Fuel CO₂ Emissions Rate: this table comprises estimated emission rates for natural gas, diesel, biodiesel and other user-defined fuels. These CO₂ emission rates are used to calculate the CO₂ production from onsite generation. They are defined as average kg of CO₂ emitted per kWh of energy content consumed in the combustion (LHV).

c. Monthly Access Fee: this table includes monthly fixed charges due to the access to the utility service. DER-CAM distinguishes between a monthly fee for electricity, natural gas, natural gas for distributed generation, natural gas for absorption chillers, and a monthly fee for diesel supply.

d. Month and Season: this table allows allocating each month to the winter or summer season, to follow with standard tariff definitions.

4.2. Electricity Rates

a. List of Hours: this table allows setting three different periods of the day, where different rates are charged: peak, mid-peak and off peak periods. Each hour can be linked to one of these Time-of-Use periods, by setting 1, 2 or 3, respectively.

b. Electricity Charges: volumetric energy costs, expressed in \$/kWh, charged by the utility. Volumetric charges are defined as Time-Of-Use rates using the three available time categories: peak, mid-peak, and off-peak hours.

c. Power Demand Charges: Power demand charges are expressed in \$/kW and can be set on a daily and/or monthly basis. Power demand charges are dependent of the maximum demand observed within a specific control period. Control periods include the peak, mid-peak, and off-peak time categories defined in the List of Hours table, in addition to coincident and non-coincident control periods. The coincident hour refers to the hour when the grid observes the global system peak, and if this component is included in the tariff, the coincident hour is set by the utility on a monthly basis. The non-coincident period considers all hours, without having to coincide with any of the remaining categories. It considers all hours of the day/month and not just a subset.

The total daily/monthly demand charge is calculated by the sum of all five components. Periods where no charge is applied should have the rate value set to zero.

4.3. Fuel Rates

Fuel rates may vary on a month-to-month basis and they are expressed in \$/kWh of fuel consumed by combustion (LHV). Estimating the cost per kWh of final energy supply is later done in DER-CAM by dividing this value by the electric conversion efficiency of the corresponding DG equipment.

Note: While utility tariffs and fuel prices may vary over the years, the DER-CAM analysis done with the main stable version considers only a single representative year where tariffs are assumed to be constant.

5. Technologies

The Technologies menu contains all relevant technological and economical information regarding the available generation and storage technologies. This information is divided in three tabs: Global Tech Definitions, Discrete Technologies, and Continuous technologies.

5.1. Global Tech Definitions

Global Tech Definitions comprise the general constraints regarding the technology investmenta, such as the total operating reserve capacity of the microgrid, the maximum generation capacity, and the maximum number of identical generation units. Also, the maximum annual fuel limits allowed as well as the infrastructure costs (e.g. controllers) associated with new DER investments can be also defined under this tab.

5.2. Discrete Technologies

Discrete technologies include micro-turbines, fuel cells and internal combustion engines – all of which with the possibility to operate in CHP mode by enabling heat recovery.

The relevant parameters used to characterize discrete technologies can be found in the DER Technology Info table, where a template list of technologies is readily available for use, although at any point these values can be manually changed. The data entered in this table allows setting the most relevant characteristics of discrete technologies, including capital costs, operation and maintenance costs, electric conversion efficiency (LHV), heat-to-power ratio, and technology lifetime, among others.

It should be noted that while a constant electric efficiency is typically used, it is possible to enable variable part-load efficiency in internal combustion engines, micro-turbines, and fuel cells by setting “efficiency_var” to 1, although this has a very significant impact on computation time.

Apart from the techno-economic characterization of discrete technologies done through this table, an additional set of constraints is also required. These constraints can be found in the Generator Constraints table and include both the minimum part-load operation, “MinLoad”, and the maximum number of hours per year each technology may operate, “MaxAnnualHours”. Properly defining these parameters allows minimizing the errors introduced by assuming constant electric conversion efficiency, as well as considering scheduled maintenance time.

Furthermore, the “MaxAnnualHours” parameter can be used to disable a specific technology by setting this value to 0.

Finally, the Generator Constraints table can be used to model existing equipment and / or force equipment in the solution. The following logic is used for this purpose:

ForcedNumber – sets the minimum number of units present in the solution

ForcedInvestment – if enabled sets the *ForcedNumber* to be the exact number of units present in the solution

Existing – if enabled sets the *ForcedNumber* of units as pre-existing

Example 1:

Force exactly two new units to be present in the solution:

ForcedInvestment = 1; ForcedNumber = 2; Existing = 0.

Example 2:

Force at least three new units to be present in the solution:

ForcedInvestment = 0; ForcedNumber = 3; Existing = 0.

Example 3:

Force at least two existing unit to be present in the solution:

ForcedInvestment = 0; ForcedNumber = 2; Existing = 1.

Example 4:

Allow any number of units to be present in the solution, where no unit already exists:

ForcedInvestment = 0; ForcedNumber = 0; Existing = 0.

Note: that this table interacts with the DiscreteInvest parameter in the Options Table found in the Global Settings menu. In particular, setting this parameter to zero globally disables all new investments in discrete technologies, and exactly the ForcedNumber will be present in the solution.

5.3. Continuous Technologies

Continuous technologies include technologies where the existing market sizes and the economies of scale allow modeling the optimal capacity using a continuous variable and defining the investment costs by a fixed and variable cost. Fixed costs are incurred regardless of the installed capacity, and can describe installation costs. Variable costs are capacity dependent, and are described per unit of capacity.

A template list of parameters to describe continuous technologies is provided by default with DER-CAM, but these values can manually be updated at any time.

Including existing equipment in a DER-CAM model follows a procedure similar to what is done with Discrete Technologies, although the *ForcedNumber* parameter is now replaced by *ForcedCapacity*. Thus, the following logic is used for this purpose:

ForcedCapacity – sets the minimum capacity present in the solution

ForcedInvestment – if enabled sets the *ForcedCapacity* to be the exact capacity present in the solution

Existing – if enabled sets the *ForcedCapacity* as pre-existing

Example 1

Force exactly 100kW of new capacity to be present in the solution:

ForcedInvestment = 1; ForcedCapacity = 100; Existing = 0.

Example 2

Force at least 200kW of new capacity to be present in the solution:

ForcedInvestment = 0; ForcedCapacity = 200; Existing = 0.

Example 3

Force at least 150 kW of existing capacity to be present in the solution:

ForcedInvestment = 0; ForcedCapacity = 150; Existing = 1.

Example 4

Allow any capacity to be present in the solution, where no capacity already exists:

ForcedInvestment = 0; ForcedCapacity = 0; Existing = 0.

All the specific continuous technologies, Storage, Heat Pump, Central HVACR and Static Switch, have their own specific technical parameters. For instance, Storage specific parameters groups specific information for electric storage, heat storage and electric vehicle such as the charging and discharging efficiency, the storage decay (portion of stored energy lost per hour due to self-discharge) and the maximum and minimum state of charge as well as charge and discharge rates. Notice that for Heat Storage these parameters are available both for high and low temperatures as DER-CAM models heat storage tanks with two temperature strata.

6. Energy Management and Resiliency

The Energy management and resiliency menu allows defining measures that do not directly represent any form of generation and / or storage, but rather influence the optimal dispatch of the available DER, and therefore may affect the investment decisions. These energy management measures include Load Shifting (LS), Demand Response (DR), and Direct Controllable Loads (DCL). During outage events, an additional type of energy management may also occur: Load Curtailment.

6.1. Load Shifting

The main difference between load shifting and the other two demand management options is the fact that, when load shifting is applied, the total energy demand remains unchanged.

Instead, a percentage of the total load of each day-type is seen as movable in time, and this percentage is user-defined. Currently, no cost is associated to this measure, which translates in high potential to shift demand from periods of high time-of-use rates to those where costs are lower. As a result, load shifting tends to flatten demand profiles, which not only leads to lower energy purchase costs, but also minimizes power demand charges. In addition to specifying how much total load can be shifted, a maximum decrease and increase per hour may also be defined. These values can be set independently for different day-types (Week and Weekend).

6.2. Demand Response

Demand response events in DER-CAM are modeled as decisions to curtail the end-use load due to price signals from the utility, if the microgrid is connected to the grid, or due to local generation costs, if the microgrid is in islanded mode. The Demand Response Parameters table defines the conditions for a potential curtailment of electric loads in the event of a demand response action. They are driven by price signals received from the utility and can be defined for three different priority levels - high, mid, and low.

The Max contribution of each priority level load is defined as a percentage of the total load. The sum of all fractions associated to each priority level must be less than or equal to 1, as this would imply allowing all load to be curtailed. On the other hand, if the sum of all fractions is lower than 1, the remaining load cannot be curtailed. In practice this can be seen as defining a fourth load type, thus effectively having non-curtable, high, mid, and low priority levels.

For each curtable load type, two parameters can be set in addition to the percentage of hourly load. These are the curtailment cost, in \$/kW, reflecting the costs incurred by the building or microgrid in the event of load curtailment, and the annual maximum number of hours that this specific type of curtailment may occur.

6.3. Direct Controllable Loads

Direct controllable loads (DCL) are modeled as 5 daily profiles, whose hourly values (in kWh) should be defined by the user in “DCL Value” table. This table should be filled taking into account that the DCL are already included in the Load Profile, which means that the sum of the 5 DCL should be less or equal than the total electric load in all periods of the day. In the “DCL and Days” table each one of the 5 profiles can be allocated to the three day-types considered in the DER-CAM (week, weekend and peak days), using a binary code (1 – allocate; 0 – do not allocate).

The main DCL parameter can be provided in a specific table “DCL Parameters”. As the curtailment decision is made, the corresponding DCL load may be curtailed partially or only entirely, according to the definition of the binary Full-LengthDCL parameter. Setting this parameter to 1 means DER-CAM will curtail the entire DCL load profile (all the 24 hours) as defined in the DCL Value table, whereas setting it to 0 will allow hourly curtailments. In the same table, the user should provide the curtailment cost, the maximum number of hours per day that the DCL can be curtailed and the conditions where the curtailment can occur, i.e., always (Outage-onlyDCL=0) or only in outage situations (Outage-onlyDCL=1). Table 1 gives a numerical example of different settings of the parameters and their implication.

Full- LengthDCL	Number of non-zero entries in DCL Value table	MaxHours	Number of days during which curtailment is possible
1	>5	5	0
0	>5	5	≤5
1	5,4 or 3	5	1
1	2	5	2
1	1	5	5

6.4. Resiliency

The resiliency subsection allows modeling medium to long term grid outages, allowing a better understanding of how resilient a microgrid is to events such as natural disasters and of which investments would be necessary to cope with grid outages. Three tables are used for this purpose: the Number of Days table, also found in the Global Settings menu, the

Electric Utility Availability table and the Load Curtailment Parameters (both for electric and heating loads).

a. Number of Days: Grid outages can only occur during emergency days. For this reason, modeling outages in DER-CAM requires specifying the corresponding number of days using this table. Namely, to model a grid outage during one single weekday in March, one 'Emergency-week' in March needs to be defined while the number of standard weekdays in March needs to be decreased by the same amount.

b. Electric Utility Availability: This table allows defining the hourly availability of the utility grid. By default, the grid is available during normal day-types and can only be set to zero during emergency days. If for example we consider one emergency weekday in March where the grid is unavailable from 11 am to 4 pm, the corresponding values must be set to zero for this 5 hour outage to be considered. If the grid availability is set to 1 for every hour the declaration of the emergency day has no impact on results as the grid is still set to be available at all times during emergency days. Likewise, setting the electric utility availability to zero is not taken into account if there is no corresponding emergency day declared for that particular day-type. The availability of the electric utility is specified on an hourly basis for each month and day-type. Sub-hourly outages can be defined, although they will only represent a drop in the hourly energy consumption, due to the fact that hourly time-steps are used.

c. Load Curtailment Parameters: it is a specific case of energy management when the utility is unavailable and the microgrid is in forced islanding. If the energy demand is greater than the local generation capacity and available storage, a percentage of the load will necessarily be curtailed. This is done at a cost to the microgrid which is the cost associated to the loss of service. Estimating this value represents a complex task that often requires visiting the site at hand and understanding all costs that may occur due to prolonged outages.

Note: If an outage is forced and curtailments are disabled ($MaxCurtailment=0$ or $MaxHours=0$) it may be necessary to enable investments in order to meet the load, as otherwise the model may become infeasible. Furthermore, it should be noted that when doing investment analysis the reference cost must reflect the outage costs in order to properly value the DER investments needed to offset the outage costs.

7. Advanced User Settings

The Advanced User Settings menu contains specific DER-CAM features consisting of two blocks: “Building Retrofit Settings” and “Financial Incentives”. In order to take these features into account they must be enabled in the Options Table under Global Settings.

7.1. Building Retrofit Settings

In addition to active generation, storage technologies, and energy management measures, it is also possible to consider building retrofits in DER-CAM as a way to minimize total energy costs and / or CO₂ emissions. Investing in passive measures will impact the energy loads, which may be a more cost-effective solution to the problem than investing in active technologies. In order to do this, DER-CAM considers changes in the overall heat transfer coefficient or U-value of different building components and estimates heat losses to gauge the impact of passive building improvements in the original energy loads input by the user. It should be noted that this is a simplified model that does not consider all forms of heat transfer and will therefore only provide guidance on whether or not building retrofits should be considered.

7.2. Financial Incentives

The standard form of financial incentive available in DER-CAM is the ability to export power back to the utility. This may be done at one of two tariff options: By net-metering, if enabled in the Global Options menu, or by setting the power exchange prices in the PX table.

7.3. SGIP

An additional part of the financial incentives is specific to the California Self-Generation Incentive Program. It contains some of the most relevant constraints that have been defined within this program, including maximum on-site capacity, efficiency constraints, feed-in tariffs, and investment subsidies.

IV. Case Study

In this section we will create a project and go through all the steps of the DER-CAM workflow to provide the user with a complete and detailed example.

1. Starting the Project

To start a new DER-CAM project please login to the site using your credentials, and when presented with the main interface select “New Project” or go to Menu File > New Project (please refer to the section *Getting started with DER-CAM* for more details).

When creating a new project you will be able to specify a unique name for it, as well as the version of DER-CAM you would like to use. Additionally, you can choose to use the existing load and solar databases. In this case study, we have selected “CaseStudy” as the project name, and selected DER-CAM Version 4.4.1.3, along with the option to use the DER-CAM databases.

The selected building is located in San Francisco, California, and consists of a large office building with Pre 1980 construction. The loads have been scaled to 1GWh, and Oakland solar data has been used (Figure 8). A medium size in San Francisco was selected.

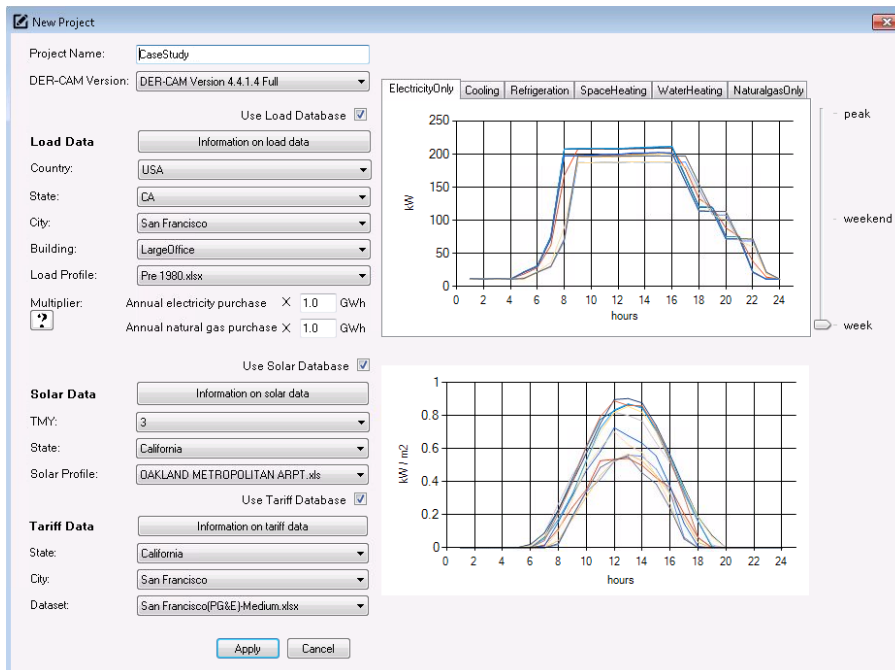


Figure 8: Creation of a new project

2. Reference Case

Before using DER-CAM to find optimal DER investment options we will need to run a base case to establish reference costs and CO₂ emissions. The first table we look at is the Options Table under Global Settings.

To do this we start by going to the Global Settings menu and in the General Options table disable all investment options by setting the first 5 parameters to zero (Figure 9). Only the parameter CentralHVACR is set to 1, because it is assumed that central HVACR is available in order to meet cooling and heating loads. All the other options are set to 0.

The purpose of this run is to properly fill the BaseCaseCost and BaseCaseCO₂ found in the ParameterTable within the Global Settings table (Figure 9). These values are set to arbitrary large numbers by default, but need to be updated before conducting meaningful investment analysis.

Options Table			Parameters Table		
	F1	F2		F1	F2
► 1	DiscreteInvest	0	1	IntRate	0.05
2	ContinuousInvest	0	2	Standby	0
3	DFChillInvest	0	3	Controt	0
4	WindInvest	0	4	turnvar	0
5	SwitchInvest	0	5	CO2Tax	0
6	NonPVSales	0	6	macroeff	0.34
7	PVSales	0	7	cooleff	0
8	NetMetering	0	8	BaseCaseCost	347630000
9	InvestmentConst	0	► 9	BaseCaseCO2	50000000
10	StandbyOpt	0	10	MaxPaybackPeriod	10
11	VaryPrice	0	11	FractionBaseLoad	0.5
12	DisableCHP	0	12	FractionPeakLoad	0.1
13	CO2Tax	0	13	ReliabilityDER	0.9
14	MinimizeCO2	0	14	MaxSpaceAvailablePVSolar	9999999
15	ZNEB	0	15	PeakPVEfficiency	0.1529
16	MultiObjective	0	16	MultiObjectiveMaxCosts	9999999
17	DiscreteElecStorage	0	17	MultiObjectiveMaxCO2	9999999
18	LS	0	18	MultiObjectiveWCosts	0.5
19	CentralHVACR	1	19	MultiObjectiveWCO2	0.5
20	CentralHVACRInvest	0	20	ZNEBsolarAreaMultiplier	9.999
21	GSHPAAnnualBalance	0	21	ZNEBCostsMultiplier	9.999
22	FuelCellConstraint	0	22	BldgShellLifetime	99
23	BuildingWallInvest	0	23	MinAnnDERGen	0
24	BuildingWindowInvest	0	24	MinAnnRENGen	0
25	BuildingDoorInvest	0	25	MaxAnnDERGen	9.99
26	BuildingRoofInvest	0	26	EpsilonBaseCaseCost	-9999999
27	BuildingGroundInvest	0	27	EpsilonMaxCO2	-9999999
			28	EpsilonMaxPayBack	-99

Figure 9: Option and Parameter Table

Finally, the Number of Days table allows setting the number of week-days, weekend-days and peak-days in each month.

Number of Days							
	F1	peak	week	weekend	emergency-week	emergency-peak	emergency-weekend
1	January	1	22	8	0	0	0
2	February	1	19	8	0	0	0
3	March	1	20	10	0	0	0
4	April	1	21	8	0	0	0
5	May	1	22	8	0	0	0
6	June	1	19	10	0	0	0
7	July	1	22	8	0	0	0
8	August	1	21	9	0	0	0
9	September	1	20	9	0	0	0
10	October	1	22	8	0	0	0
11	November	1	20	9	0	0	0
12	December	1	21	9	0	0	0

Figure 10: Number of days Table

Following, we go to the Site Weather settings section. In this case study we have selected solar insolation profiles from the database and use the default settings for ambient temperature, other locational data and wind power potential. However, these values can be updated at any moment if necessary.

Solar Insolation

	month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
▶	1	january	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0198	0.1865	0.3385	0.4140	0.5226	0.5605	0.5536	0.4764	0.3352	0.0636	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	2	february	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0443	0.1752	0.3081	0.4368	0.5255	0.5674	0.5252	0.4393	0.3261	0.1777	0.0330	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	3	march	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0168	0.1151	0.2447	0.3528	0.5265	0.5351	0.5406	0.4973	0.4237	0.3645	0.2047	0.0617	0.0014	0.0000	0.0000	0.0000	0.0000	0.0000
	4	april	0.0000	0.0000	0.0000	0.0000	0.0000	0.0011	0.0637	0.2272	0.4172	0.6075	0.7764	0.8286	0.8656	0.8544	0.7040	0.5251	0.3303	0.1591	0.0064	0.0000	0.0000	0.0000	0.0000	0.0000
	5	may	0.0000	0.0000	0.0000	0.0000	0.0000	0.0153	0.0921	0.2660	0.4408	0.5783	0.7160	0.8196	0.7998	0.7664	0.6345	0.5133	0.3230	0.1572	0.0169	0.0000	0.0000	0.0000	0.0000	0.0000
	6	june	0.0000	0.0000	0.0000	0.0000	0.0000	0.0210	0.0884	0.2295	0.3973	0.5694	0.7506	0.8964	0.9025	0.8761	0.7401	0.5619	0.3671	0.1869	0.0749	0.0003	0.0000	0.0000	0.0000	0.0000
	7	july	0.0000	0.0000	0.0000	0.0000	0.0000	0.0110	0.0708	0.1759	0.3116	0.5234	0.6982	0.8176	0.8543	0.8192	0.7006	0.5372	0.3577	0.1835	0.0662	0.0001	0.0000	0.0000	0.0000	0.0000
	8	august	0.0000	0.0000	0.0000	0.0000	0.0000	0.0013	0.0534	0.1714	0.3259	0.5275	0.7249	0.8339	0.8706	0.8442	0.7158	0.5537	0.3468	0.1615	0.0047	0.0000	0.0000	0.0000	0.0000	0.0000
	9	september	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0434	0.2064	0.3958	0.6137	0.7935	0.8887	0.8603	0.8583	0.7249	0.5332	0.3091	0.0635	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
	10	october	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0117	0.1567	0.3146	0.4654	0.5820	0.7259	0.6768	0.6320	0.5554	0.3707	0.1469	0.0079	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	11	november	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1029	0.2942	0.4852	0.6033	0.7014	0.6222	0.5764	0.4317	0.2684	0.0513	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	12	december	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0256	0.1915	0.3417	0.4861	0.5332	0.5518	0.4532	0.3859	0.2380	0.0544	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Ambient Hourly Temperature

	F1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
▶	1	January	8.1	7.9	7.8	7.7	7.8	7.9	8	8.9	9.7	10.6	11.5	12.4	13.3	13.4	13.6	13.8	12.8	11.9	10.9	10.4	9.9	9.3	8.9	8.5
	2	February	9.7	9.5	9.3	9.1	8.8	8.6	8.2	9.5	10.7	12	13.2	14.4	15.5	15.6	15.7	15.8	14.9	13.9	13	12.3	11.7	11.1	10.5	10.1
	3	March	11.1	10.6	10.1	9.6	9.3	9	8.7	9.9	11.1	12.3	13.4	14.5	15.6	15.9	16.1	16.4	15.6	14.8	14	13.6	13.1	12.6	12.1	11.6
	4	April	10.3	9.8	9.4	9	9.4	9.7	10.1	11.5	13	14.5	15.6	16.8	18	18.1	18.2	18.4	17	15.5	14.1	13.5	12.9	12.2	11.5	10.8
	5	May	11.2	11.1	10.8	10.4	10.9	11.3	11.7	13.2	14.6	16.1	17.5	18.9	20.4	20.2	20	19.8	18.2	16.6	15	14	13.2	12.2	11.7	11.5
	6	June	13	12.9	12.7	12.3	12.9	13.6	14.2	15.5	16.7	18	19.4	20.7	22	21.6	21.1	20.7	19.3	17.8	16.4	15.5	14.7	13.8	13.3	13.1
	7	July	13.4	13.3	13.1	13	13.4	13.7	14.1	15.5	16.9	18.3	19.8	21.3	22.8	22.4	22.1	21.8	20.2	18.6	17.1	16.3	15.5	14.7	14	13.7
	8	August	14	13.8	13.6	13.4	13.5	13.7	13.9	15.2	16.5	17.9	19.6	21.4	23.1	22.6	22.1	21.6	20.1	18.5	17.1	16.3	15.7	14.9	14.4	14.1
	9	September	14.8	14.5	14.1	13.7	13.5	13.7	14.7	16.2	17.7	19	20.6	22.2	23.4	23.6	23.2	22.4	21.3	19.5	18.2	17.2	16.6	16.1	15.6	15.2
	10	October	13.4	12.9	12.4	11.9	12.1	12.3	12.5	14.2	15.8	17.4	18.6	19.9	21.1	21.2	21.2	21.3	19.9	18.6	17.2	16.6	16	15.3	14.6	13.9
	11	November	10.8	10.2	9.6	9.2	9.3	9.3	9.9	11.5	13.4	14.4	15.3	16.6	17.1	17.4	17.3	16.3	15	14.1	13.3	12.7	11.9	11.7	11.5	11.2
	12	December	8.2	7.9	7.4	6.9	6.9	7	7	8.1	9.3	10.4	11.5	12.6	13.6	13.8	13.9	14.1	13	12	11	10.3	9.7	9.1	8.6	8.3

Other Location Data		
	F1	F2
► 1	WindSpeed	5

Figure 11: "Site Weather Settings" Tables

Wind Power Potential																												
	F1	F2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	↕	
▶	1	January	week	5.84	6.3	7.23	8.2	10.22	7.88	5.29	5.72	7	6.65	7.43	9.03	9.24	8.28	7.87	6.65	4.62	4.52	3.76	4.47	4.72	4.92	5.23	7.65	
2	February	week	9.86	10.24	10.93	7.43	6.37	5.17	6.02	6.7	4.96	5.46	7.01	7.97	7.91	9	8.23	7.82	7.32	6.88	6.51	5.81	5.23	6.52	8.35	10.17		
3	March	week	19.72	20.33	18.97	17.22	14.31	12.09	12.16	13.64	14.99	14.28	13.77	14.46	13.77	13.07	11.83	11.59	10.25	9.51	10.14	10.27	13.27	14.5	17.48	20.01		
4	April	week	14.27	12.49	9.87	10.21	8.93	9.55	8.87	7.05	7.29	7.62	7.11	6.55	5.99	5.38	7.82	6.82	4.8	5.88	7.32	8.38	9.41	13.05	15.14	18.01		
5	May	week	12.3	12.73	10.8	8.21	7.14	7.38	7.12	5.96	4.69	3.5	3.02	2.5	2.07	2.5	3.05	2.81	2.92	4.27	4.67	5.21	5.7	6.91	9	12.45		
6	June	week	11.73	10.83	9.51	9.09	9.09	9.14	8.97	7.51	7.72	7.33	5.04	4.21	3.43	2.97	1.92	1.29	1.3	1.48	2.23	2.33	2.86	4.13	6.61	13.1		
7	July	week	13.19	11.47	11.73	13.47	13.05	11.77	11.2	9.49	7.74	6.2	4.72	2.89	2.19	1.62	1.33	0.63	1.23	2.15	3.01	3.82	4.55	5.51	7.62	11.68		
8	August	week	8.75	7.54	6.6	6.69	5.63	4.32	4.35	3.69	3.03	2.1	1.98	1.66	1.54	1.41	1.06	0.78	0.67	0.69	0.92	1.34	1.82	2.31	4.02	6.77		
9	September	week	6.97	6.3	6.58	5.03	4.17	4.09	4.03	3.02	2.18	1.33	0.93	0.48	1.02	1.31	1.63	1.85	1.96	3.36	4.13	4.73	4.68	4.15	4.95	7.76		
10	October	week	9.04	6.87	7.33	5.97	5.23	5.21	3.76	2.89	2	2.01	1.95	2.05	2.29	1.97	1.85	1.95	1.83	1.23	1.73	2.3	2.64	2.35	3.32	6.01		
11	November	week	7.35	8.04	6.73	7.07	5.88	4.3	4.3	2.99	3.2	2.63	1.97	1.98	1.03	0.94	0.82	0.99	1.35	2.32	2.82	3.45	3.47	3.47	4.38	7.21		
12	December	week	7.26	6.54	5.73	7.69	6.82	7.26	5.96	6.53	6.29	6.16	5.21	5.33	5.46	4.69	5.11	6.51	6.91	7.96	7.65	7.95	8.96	9.37	8.94	9.13		
13	January	peak	5.84	6.3	7.23	8.2	10.22	7.88	5.29	5.72	7	6.65	7.43	9.03	9.24	8.28	7.87	6.65	4.62	4.52	3.76	4.47	4.72	4.92	5.23	7.65		
14	February	peak	9.86	10.24	10.93	7.43	6.37	5.17	6.02	6.7	4.96	5.46	7.01	7.97	7.91	9	8.23	7.82	7.32	6.88	6.51	5.81	5.23	6.52	8.35	10.17		
15	March	peak	19.72	20.33	18.97	17.22	14.31	12.09	12.16	13.64	14.99	14.28	13.77	14.46	13.77	13.07	11.83	11.59	10.25	9.51	10.14	10.27	13.27	14.5	17.48	20.01		
16	April	peak	14.27	12.49	9.87	10.21	8.93	9.55	8.87	7.05	7.29	7.62	7.11	6.55	5.99	5.38	7.82	6.82	4.8	5.88	7.32	8.38	9.41	13.05	15.14	18.01		
17	May	peak	12.3	12.73	10.8	8.21	7.14	7.38	7.12	5.96	4.69	3.5	3.02	2.5	2.07	2.5	3.05	2.81	2.92	4.27	4.67	5.21	5.7	6.91	9	12.45	↔	
18	June	peak	11.73	10.83	9.51	9.09	9.09	9.14	8.97	7.51	7.72	7.33	5.04	4.21	3.43	2.97	1.92	1.29	1.3	1.48	2.23	2.33	2.86	4.13	6.61	13.1		
19	July	peak	13.19	11.47	11.73	13.47	13.05	11.77	11.2	9.49	7.74	6.2	4.72	2.89	2.19	1.62	1.33	0.63	1.23	2.15	3.01	3.82	4.55	5.51	7.62	11.68		
20	August	peak	8.75	7.54	6.6	6.69	5.63	4.32	4.35	3.69	3.03	2.1	1.98	1.66	1.54	1.41	1.06	0.78	0.67	0.69	0.92	1.34	1.82	2.31	4.02	6.77		
21	September	peak	6.97	6.3	6.58	5.03	4.17	4.09	4.03	3.02	2.18	1.33	0.93	0.48	1.02	1.31	1.63	1.85	1.96	3.36	4.13	4.73	4.68	4.15	4.95	7.76		
22	October	peak	9.04	6.87	7.33	5.97	5.23	5.21	3.76	2.89	2	2.01	1.95	2.05	2.29	1.97	1.85	1.95	1.83	1.23	1.73	2.3	2.64	2.35	3.32	6.01		
23	November	peak	7.35	8.04	6.73	7.07	5.88	4.3	4.3	2.99	3.2	2.63	1.97	1.98	1.03	0.94	0.82	0.99	1.35	2.32	2.82	3.45	3.47	3.47	4.38	7.21		
24	December	peak	7.26	6.54	5.73	7.69	6.82	7.26	5.96	6.53	6.29	6.16	5.21	5.33	5.46	4.69	5.11	6.51	6.91	7.96	7.65	7.95	8.96	9.37	8.94	9.13		
25	January	weekend	8.42	4.64	5.04	4.57	3.23	3.97	3.84	4.09	2.45	5.09	5.82	6.68	6.3	6.72	7.81	8.24	7.93	8.01	8.24	9.19	11.37	13.59	13.01	7.98		
26	February	weekend	4.04	3.92	5.45	5.38	2.87	2.56	3.42	1.45	3.39	5.15	6.55	5.85	4.39	6.79	8.04	9.42	10.78	6.53	3.48	0.9	1.21	2.3	2.84	6.33		
27	March	weekend	22.61	17.72	15.75	21.65	20.08	18.29	19.12	14.4	10.73	13.12	14.27	13.04	10.73	9.84	9.05	11.32	11.83	11.41	11.29	12.03	13.12	14.38	15.27	17.21		
28	April	weekend	22.75	23.49	22.22	22.22	22.6	24.36	20.99	18.44	15.81	12.96	13.7	10.04	8.97	9.25	8.13	6.44	6.04	7.07	8.08	9.43	10.29	14.25	14.4	17.38		
29	May	weekend	20.2	16.78	13.87	14.5	16.28	13.71	14.06	10.57	5.8	5.37	4.2	2.94	3.57	3.04	2.03	2.09	4.53	6.44	5.01	4.6	6.31	8.57	10.11	13.07		
30	June	weekend	11.17	10.76	9.06	9.02	8.67	7.12	7.2	6.55	5.49	4.15	2.76	2.69	1.88	0.76	0.48	0.12	0.36	0.52	0.68	1.38	2.36	4	6.43	9.07		
31	July	weekend	11.23	8.82	7.91	7.88	8.69	7.32	6.35	5.85	6.11	5.04	5.33	4.97	4.73	4.09	3.57	1.22	0.91	1.23	1.67	1.84	2.95	4.43	7.09	11.41		

Figure 12: Wind Power Potential

Following the Site Weather Settings we find the Load Profiles (Figure 13). Once again, we have opted to use the existing DER-CAM database to pre-fill this information, but it is still available for any necessary edits.

Load																		
	type	month	daytype	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	electricity-only	January	week	12.4037	11.1747	12.4979	11.2670	12.8526	21.1914	29.6050	68.5205	187.2892	186.7837	187.7177	187.1291	188.2167	187.5399	188.1616
2	electricity-only	February	week	11.0849	11.0990	11.0990	11.1453	11.0990	21.4868	30.0853	71.5052	195.9487	195.9269	196.0441	196.2943	196.5882	196.9961	197.0919
3	electricity-only	March	week	11.1132	11.0744	11.1400	11.1078	18.8682	28.4688	62.0700	167.8094	207.4891	207.5091	207.6173	207.8459	208.1608	208.4571	208.7488
4	electricity-only	April	week	11.0990	11.0668	11.0990	11.0779	22.1347	31.2348	75.2859	207.5030	207.6862	207.9311	207.8882	207.7216	208.4387	208.6189	209.0926
5	electricity-only	May	week	11.0147	11.0147	11.0147	11.0326	21.4966	30.2498	72.0724	197.8825	198.5649	198.5205	198.9438	198.0662	198.8017	199.5214	199.9316
6	electricity-only	June	week	11.0147	11.0147	11.0147	11.0147	22.0294	31.2833	75.2859	207.7766	208.2551	208.6460	208.6463	208.0392	208.8865	209.3903	210.4003
7	electricity-only	July	week	11.0147	11.0147	11.0147	11.0147	21.4175	30.1705	72.0790	196.8466	197.7895	197.8764	198.2822	197.2262	198.0554	198.9170	199.7931
8	electricity-only	August	week	11.0147	11.0147	11.0147	11.0147	22.0294	31.3169	75.2859	207.8517	208.4164	208.8568	208.9879	208.4492	209.6376	210.4127	211.1925
9	electricity-only	September	week	11.0147	11.0147	11.0147	11.0147	21.4175	30.1966	71.7153	196.9652	197.5706	198.1256	199.1113	198.6489	200.7379	201.1038	202.2594
10	electricity-only	October	week	11.0147	11.0147	11.0147	11.0147	21.4497	30.2280	71.9032	197.2579	197.6800	198.4820	199.7510	199.5534	201.6945	201.8944	202.4910
11	electricity-only	November	week	11.0901	11.0147	11.1341	11.0775	12.9046	22.4319	36.0561	89.4533	186.8641	186.9545	187.5811	187.5199	188.4293	188.0640	188.3649
12	electricity-only	December	week	11.9972	11.0943	12.0478	11.1639	12.2006	21.6164	30.6000	71.7153	197.0425	196.5496	197.0481	196.8252	197.3099	197.0247	197.3550
13	electricity-only	January	peak	11.0147	11.4324	11.0147	11.4921	11.0147	22.6659	31.2271	75.2859	207.4624	207.4657	208.3618	209.6770	210.2696	211.0535	211.2309
14	electricity-only	February	peak	11.0147	11.0147	11.0147	11.0147	22.0294	31.2487	75.2859	207.4648	207.6427	208.7783	210.3409	210.6034	211.7469	212.5703	212.1123
15	electricity-only	March	peak	11.0147	11.0147	11.0147	11.0147	14.8454	25.0953	45.9406	119.3449	207.6184	207.7448	208.3754	209.3273	209.9345	210.8677	211.4572
16	electricity-only	April	peak	11.0147	11.0147	11.0147	11.0147	22.0294	31.3252	75.2859	208.3739	209.3958	210.0648	210.8260	210.1445	212.0535	213.1881	214.2175
17	electricity-only	May	peak	11.0147	11.0147	11.0147	11.0147	22.0294	31.3513	75.2859	208.1379	209.1944	209.7926	209.7151	208.6518	209.9252	210.9286	212.0400
18	electricity-only	June	peak	11.0147	11.0147	11.0147	11.0147	22.0294	31.4033	75.2859	209.0719	210.3731	211.0856	210.9433	209.6268	211.2121	212.4386	213.8369
19	electricity-only	July	peak	11.0147	11.0147	11.0147	11.0147	22.0294	31.3716	75.3371	208.8976	209.8601	210.7581	210.8884	209.7230	211.6691	212.6707	213.8342
20	electricity-only	August	peak	11.0147	11.0147	11.0147	11.0147	22.0294	31.3481	75.2859	208.0625	208.8739	209.6105	210.2095	209.7716	211.5060	212.2781	213.2146
21	electricity-only	September	peak	11.0147	11.0147	11.0147	11.0147	22.0294	31.4848	75.2859	209.1123	211.2219	213.9799	216.5264	215.8077	219.9743	223.1435	226.7646
22	electricity-only	October	peak	11.0147	11.0147	11.0147	11.0147	22.0294	31.3367	75.2859	207.7311	208.5682	210.4540	212.1171	212.2746	214.6425	216.1504	216.9549
23	electricity-only	November	peak	11.0147	11.0147	11.0147	11.0147	22.0294	31.2384	75.2859	207.4624	207.6685	208.7869	210.1706	210.0427	211.4407	212.1585	211.3538
24	electricity-only	December	peak	11.0147	11.0147	11.0147	11.0147	22.1488	31.2271	75.2859	207.4624	207.4641	207.7163	208.5663	209.2611	210.0271	210.3948	209.7023
25	electricity-only	January	weekend	12.0025	11.1181	12.0025	11.3529	12.0025	11.4125	20.9857	20.1571	60.2287	59.3205	60.1492	60.1187	60.2264	60.3969	25.8518
26	electricity-only	February	weekend	11.0147	11.0147	11.0147	11.1191	11.0147	11.2832	21.1239	21.2999	65.1797	65.3642	66.1954	65.5894	67.5951	66.7569	29.1539
27	electricity-only	March	weekend	11.0147	11.0744	11.0147	11.1490	11.1042	16.3065	21.2108	43.3293	65.2692	65.3527	65.9711	66.3908	66.6648	47.4318	27.9171
28	electricity-only	April	weekend	11.0147	11.0147	11.0147	11.0505	11.0863	21.2766	21.1925	65.4162	66.0181	65.4137	65.9667	65.2634	66.0506	26.7270	27.5453
29	electricity-only	May	weekend	11.0147	11.0147	11.0147	11.0595	11.0147	21.2276	21.1209	65.2536	67.1202	65.2984	65.1797	65.1797	65.1797	26.6953	29.9104
30	electricity-only	June	weekend	11.0147	11.0147	11.0147	11.0147	11.0147	21.1603	21.1209	65.3222	66.6381	66.3713	66.4175	65.2260	65.2170	28.1860	27.8411
31	electricity-only	July	weekend	11.0147	11.0147	11.0147	11.0147	11.0147	21.1769	21.7340	66.8703	66.4833	67.3109	66.3285	66.9228	66.0521	28.0857	29.4173

Figure 13: Loads Table

The Utility menu is then used to define the relevant utility tariffs. In this case, we are using a PG&E tariff considering a medium peak load (between 200 kW and 500 kW). This tariff consists of time-of-use energy rates, defined over three control periods: peak, shoulder, off-peak, varying on a monthly basis. It also includes a peak demand charges applied the maximum monthly demand observed during non-coincident periods and an access fee of 137.97 \$/month. Fuel prices can be also defined in Fuel Rates tab of the utility menu (Figure 15).

Electricity Rates			
	month	on	mid
1	January		0.1275
2	February		0.1275
3	March		0.1275
4	April		0.1275
5	May	0.17891	0.17087
6	June	0.17891	0.17087
7	July	0.17891	0.17087
8	August	0.17891	0.17087
9	September	0.17891	0.17087
10	October	0.17891	0.17087
11	November		0.1275
12	December		0.1275

Monthly Access Fee	
utility	value
1	UtilElectric 137.97
2	UtilNGbasic 15.63
3	UtilNGforDG 15.63
4	UtilNGforABS 15.63
5	UtilDiesel 0

Monthly Demand Rates						
	month	coincident	noncoincident	onpeak	midpeak	offpeak
1	January	0	7.31	0	0	0
2	February	0	7.31	0	0	0
3	March	0	7.31	0	0	0
4	April	0	7.31	0	0	0
5	May	0	15.54	0	0	0
6	June	0	15.54	0	0	0
7	July	0	15.54	0	0	0
8	August	0	15.54	0	0	0
9	September	0	15.54	0	0	0
10	October	0	15.54	0	0	0
11	November	0	7.31	0	0	0
12	December	0	7.31	0	0	0

List of Hours																										
	season	period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
▶ 1	Summer	peak	3	3	3	3	3	3	3	3	2	2	2	1	1	1	1	1	1	1	2	2	2	2	3	3
2	Summer	week	3	3	3	3	3	3	3	3	2	2	2	1	1	1	1	1	1	1	2	2	2	2	3	3
3	Summer	weekend	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	Winter	peak	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
5	Winter	week	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3
6	Winter	weekend	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Figure 14: Tariff tables in DER-CAM

Fuel Price							
	month	Ngbasic	NGforDG	NGforAbs	Diesel	BioDiesel	Other
1	January	0.029192833	0.025192833	0.029192833	0.0832	0	0
2	February	0.029192833	0.025192833	0.029192833	0.0832	0	0
3	March	0.029192833	0.025192833	0.029192833	0.0832	0	0
4	April	0.029192833	0.025192833	0.029192833	0.0832	0	0
5	May	0.025516382	0.020516382	0.025516382	0.0832	0	0
6	June	0.025516382	0.020516382	0.025516382	0.0832	0	0
7	July	0.025516382	0.020516382	0.025516382	0.0832	0	0
8	August	0.025516382	0.020516382	0.025516382	0.0832	0	0
9	September	0.025516382	0.020516382	0.025516382	0.0832	0	0
10	October	0.025516382	0.020516382	0.025516382	0.0832	0	0
11	November	0.029192833	0.025192833	0.029192833	0.0832	0	0
12	December	0.029192833	0.025192833	0.029192833	0.0832	0	0

Figure 15: Fuel Price table

Settings regarding marginal CO₂ emissions as well as CO₂ emissions from burning fuel (Figure 16) can also be changed in the Utility menu under Global Settings Tab. The predefined values of the CO₂ emissions rate are obtained from CAISO (Californian Independent System Operator) in combination with the U.S. Energy Information Administration (EIA), and the fuel emissions rate are estimated using average heating content values obtained from EIA.

Marginal CO2 Emissions


	F1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
▶ 1	January	0.481746583	0.480936526	0.494054128	0.486273062	0.485150078	0.509145785	0.525330791	0.516663906	0.507155512	0.497523708	0.504104566	0.503535631	0.508636132	0.492484539	0.51061657
2	February	0.504965908	0.521956621	0.507946724	0.53068471	0.516157864	0.506402525	0.507069358	0.5293347	0.509769645	0.503835412	0.492813116	0.486018443	0.489844955	0.50105223	0.496736778
3	March	0.5053582	0.556058867	0.557902993	0.547899422	0.529392109	0.520293926	0.500453832	0.501196474	0.486287422	0.484293627	0.474786678	0.482221377	0.482418787	0.486844493	0.49357254
4	April	0.524414291	0.546542175	0.616499733	0.604602223	0.559804894	0.502737779	0.532098798	0.509197359	0.50796506	0.501644473	0.502819122	0.506566405	0.498736634	0.505787333	0.507096548
5	May	0.531052814	0.564394651	0.580164246	0.565106113	0.544601901	0.495560258	0.522344909	0.51348947	0.499671515	0.485817883	0.483296476	0.491006655	0.48057768	0.481858705	0.496508353
6	June	0.500379835	0.485026777	0.539777959	0.538613995	0.428604814	0.49317292	0.513156044	0.509790898	0.460039986	0.483845887	0.496333347	0.469993837	0.502262812	0.514911172	0.514323199
7	July	0.482737281	0.496777447	0.48369147	0.490346581	0.504696274	0.492577859	0.492545235	0.511379084	0.517888908	0.517763346	0.516429018	0.53896249	0.556764008	0.51482879	0.48155186
8	August	0.519714278	0.511717295	0.52002478	0.518496413	0.534491071	0.518157568	0.51258708	0.491244194	0.505201984	0.519342537	0.535581403	0.540975659	0.532140653	0.544072205	0.510542488
9	September	0.511319061	0.480955649	0.492512363	0.511786053	0.485706068	0.532907631	0.50653321	0.516833168	0.5269343	0.518591994	0.517868893	0.540586242	0.541014058	0.511214335	0.543120744
10	October	0.489221462	0.495747928	0.50143607	0.506515208	0.516648487	0.502418965	0.529823131	0.529581737	0.513463098	0.504507803	0.51513967	0.510499716	0.523030811	0.508510248	0.509772396
11	November	0.503811212	0.499479136	0.503063669	0.514076285	0.501754091	0.492877271	0.520685843	0.502337031	0.523283088	0.508793314	0.510443889	0.503323776	0.515631365	0.511405326	0.516234281
12	December	0.486977303	0.50697829	0.505844562	0.502001081	0.51668905	0.501390618	0.523289251	0.508057703	0.517834019	0.503992296	0.497395331	0.505513615	0.521762796	0.510844657	0.510961287

Fuel CO2 Emissions Rate

	F1	F2
▶ 1	NGbasic	0.18108
2	NGforDG	0.18108
3	NGforAbs	0.18108
4	Diesel	0.24964
5	BioDiesel	0.0757
6	Other	0

Figure 16: CO₂ emissions tables in DER-CAM

Even that the purpose of this initial run is to determine only the reference costs for the investment analysis, the Technology segment does not require any changes unless there is already existing equipment at the site. In this particular case we will assume this is not the case, and will address DER technologies later on. Similarly, Energy Management and Resiliency options will not be considered in this reference run.

Once all the input parameters have been revised, click on  button in the toolbar to run the optimization. The results window will appear shortly after (Figure 17).

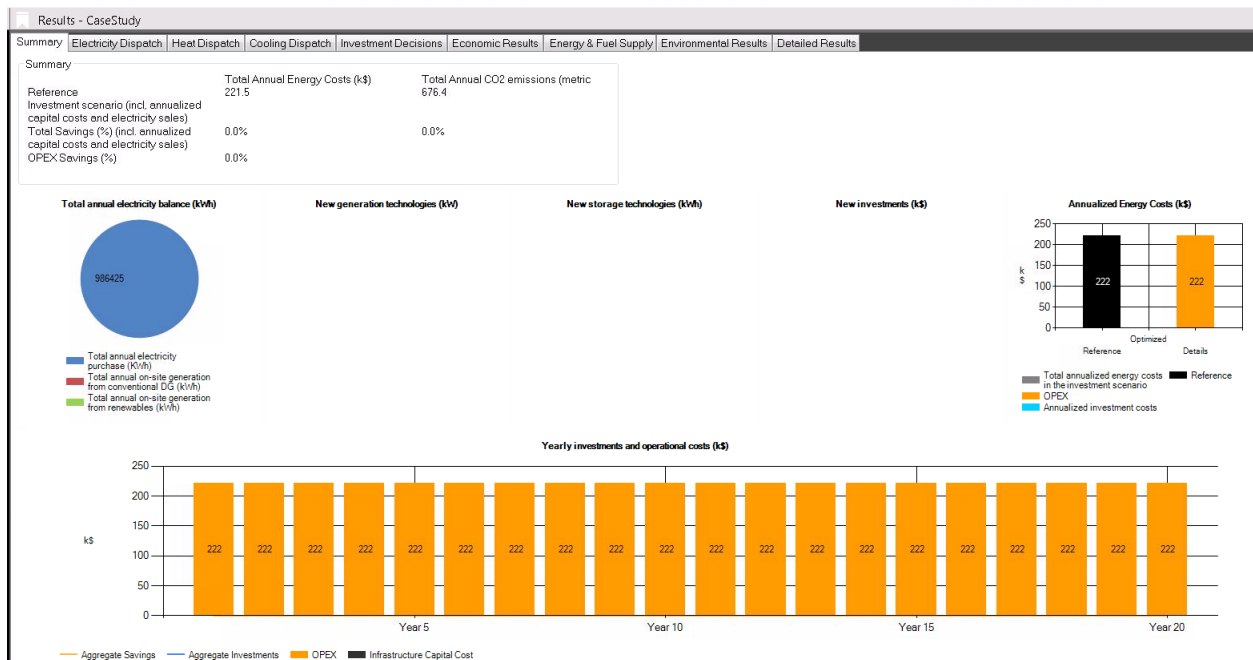


Figure 17: Result View, Summary Sheet

Results - CaseStudy									
Summary	Electricity Dispatch	Heat Dispatch	Cooling Dispatch	Investment Decisions	Economic Results	Energy & Fuel Supply	Environmental Results	Detailed Results	
	F1	F2	F3	F4	F5	F6	F7	F8	
104									
105	6. Input Data								
106	6.1 Key Model Options								
107	6.2 Aggregated Loads								
108	6.3 Detailed Load								
109									
110	+++++ Summary +++++								
111									
112	Total Annual Energy Costs (incl. annualized capital c...	221510							
▶ 113	Total Annual CO2 emissions (kg)	676367							
114									
115									
116	+++ 1. INVESTMENT DECISIONS								
117	+++++ 1.1 Local Generation								
118	Discrete technology Selection								
119		Capacity (kW)	Existing Units	Age	New Units	Lifetime			
120									
121									

Figure 18: Results View, Detailed Results Sheet

The base case cost and the base case CO₂ are the highlighted values, respectively \$221510 and 676367 kg. Now that the values of these parameters are obtained we can insert them in the Parameter Table under Global Settings. Note that you should add 1 % of their values to guarantee feasibility, which is the default solver precision.

3. Cost Minimization

After performing the base case or reference case, investment analysis may be conducted. To do this, we have updated the BaseCaseCost and BaseCaseCO2 parameters in the Parameter Table found in the Global Settings menu, and other financial parameters must now be defined, including the project “InterestRate” and the “MaxPaybackPeriod”. It should be noted that whenever performing investment analysis all financial constraints must be verified, regardless of the objective being economic or environmental. For this reason, if the maximum project payback is set to be too short, the investments may be limited or inexistent. In this case study we have set the maximum payback period equal to 10 years and the interest rate to be 5% (Figure 19).

To enable investments we now update the “DiscreteInvest” and “ContinuousInvest” parameters, which will generically allow investments all technologies that fall within these groups (Figure 19). Further down we will refine this by defining which technologies we are interested in within these groups.

Parameters Table				
	F1	F2		
1	IntRate	0.05		
2	Standby	0		
3	Contract	0		
4	turnvar	0		
5	CO2Tax	0.272727		
6	macroeff	0.34		
7	cooleff	0		
8	BaseCaseCost	221510		
9	BaseCaseCO2	676367	DiscreteInvest	1
10	MaxPaybackPeriod	10	ContinuousInvest	1

Figure 19: Parameter and Option Table

Given that all other relevant areas were defined to calculate the reference cost, we can now focus on the Technologies section, starting with discrete technologies.

Under Generator constraints we find the table that will allow us to enable or disable specific technologies depending on our needs (Figure 20). Please note that the technologies where “FixedInvest” is set to 1 are disabled and cannot be selected in the optimization. In this case study we are only considering the first 14 technologies, as seen in Figure 22, and have allowed them to run freely up to 8147 and 8585 hours of the year. Furthermore, we do not want to force a number of technologies to be installed, but rather want DER-CAM to freely choose on the optimum number of technologies. This is done by setting “ForcedNumber” to Zero (Figure 20). In this case study we are using the default techno-economic parameters for all 14 technologies enabled, but at any moment the existing values can be updated to better reflect any specific project needs (Figure 21).

Generator Constraints								
	F1	MinAnnualHours	MaxAnnualHours	MinLoad	FixedInvest	ForcedNumber	ExistingYN	Age
▶ 1	ICE_RB_75	0	8147	0.7	0	0	0	0
2	ICE_RB_250	0	8147	0.7	0	0	0	0
3	ICE_LB_500	0	8147	0.7	0	0	0	0
4	ICE_LB_750	0	8147	0.7	0	0	0	0
5	ICE_LB_1000	0	8147	0.7	0	0	0	0
6	ICE_LB_2500	0	8147	0.7	0	0	0	0
7	ICE_LB_5000	0	8147	0.7	0	0	0	0
8	MT_65	0	8322	0.75	0	0	0	0
9	MT_200	0	8322	0.75	0	0	0	0
10	MT_250	0	8322	0.75	0	0	0	0
11	MT_1000	0	8322	0.75	0	0	0	0
12	CT_3500	0	8322	0.7	0	0	0	0
13	CT_5000	0	8322	0.7	0	0	0	0
14	CT_7500	0	8322	0.7	0	0	0	0
15	CT_15000	0	8322	0.7	1	0	0	0
16	CT_25000	0	8322	0.7	1	0	0	0
17	MCFC_300	0	8585	1	1	0	0	0
18	PAFC_400	0	8585	1	1	0	0	0
19	MCFC_1000	0	8585	1	1	0	0	0
20	MCFC_1400	0	8585	1	1	0	0	0
21	MCFC_2800	0	8585	1	1	0	0	0
22	ICE_RB_CHP-HW_75	0	8147	0.7	1	0	0	0
23	ICE_RB_CHP-HW_250	0	8147	0.7	1	0	0	0
24	ICE_LB_CHP-HW_500	0	8147	0.7	1	0	0	0
25	ICE_LB_CHP-HW_750	0	8147	0.7	1	0	0	0
26	ICE_LB_CHP-HW_1000	0	8147	0.7	1	0	0	0
27	ICE_LB_CHP-HW_2500	0	8147	0.7	1	0	0	0
28	ICE_LB_CHP-HW_5000	0	8147	0.7	1	0	0	0
29	MT_CHP-HW_65	0	8322	0.75	1	0	0	0
30	MT_CHP-HW_200	0	8322	0.75	1	0	0	0

Figure 20: Generation Constraints

DER Technologies Info																
	F1	maxp	lifetime	capcost	OMFix	OMVar	SprintCap	SprintHours	Fuel	Type	efficiency	efficiency_var	alpha	Chpenable	BackupOnly	SGIPIncentive
1	ICE_RB_75	75	15	2230.222222	0	0.024	75	0	3	4	0.26	0	0	0	0	0
2	ICE_RB_250	250	15	2073.066667	0	0.024	250	0	3	4	0.27	0	0	0	0	0
3	ICE_LB_500	500	15	1814.057143	0	0.021	500	0	3	4	0.33	0	0	0	0	0
4	ICE_LB_750	750	20	1752.089552	0	0.021	750	0	3	4	0.345	0	0	0	0	0
5	ICE_LB_1000	1000	20	1521	0	0.019	1000	0	3	4	0.368	0	0	0	0	0
6	ICE_LB_2500	2500	20	1284.301887	0	0.016	2500	0	3	4	0.404	0	0	0	0	0
7	ICE_LB_5000	5000	20	923.6842105	0	0.0085	5000	0	3	4	0.416	0	0	0	0	0
8	MT_65	65	15	2737	0	0.013	65	0	3	5	0.238	0	0	0	0	0
9	MT_200	200	15	2677.5	0	0.016	200	0	3	5	0.267	0	0	0	0	0
10	MT_250	250	15	2311.15	0	0.011	250	0	3	5	0.261	0	0	0	0	0
11	MT_1000	1000	15	2125	0	0.012	1000	0	3	5	0.267	0	0	0	0	0
12	CT_3500	3500	20	2524.216102	0	0.01	3500	0	3	2	0.2396	0	0	0	0	0
13	CT_5000	5000	20	1634.866439	0	0.009	5000	0	3	2	0.2891	0	0	0	0	0
14	CT_7500	7500	20	1589.702513	0	0.0089	7500	0	3	2	0.2734	0	0	0	0	0
15	CT_15000	15000	20	1226.535208	0	0.0062	15000	0	3	2	0.3325	0	0	0	0	0
16	CT_25000	25000	20	1018.022163	0	0.0062	25000	0	3	2	0.3597	0	0	0	0	0
17	MCFC_300	300	20	10000	0	0.045	300	0	3	1	0.427272727	0	0	0	0	0
18	PAFC_400	400	20	7000	0	0.036	400	0	3	1	0.381818182	0	0	0	0	0
19	MCFC_1000	1000	20	6160	0	0.035	1000	0	3	1	0.4273	0	0	0	0	0
20	MCFC_1400	1400	20	4400	0	0.035	1400	0	3	1	0.427272727	0	0	0	0	0
21	MCFC_2800	2800	20	4000	0	0.035	2800	0	3	1	0.4273	0	0	0	0	0
22	ICE_RB_CHPHW_75	75	15	2880.703704	0	0.0255	75	0	3	4	0.26	0	2.0064440538461539	1	0	0
23	ICE_RB_CHPHW_250	250	15	2613.966667	0	0.025	250	0	3	4	0.27	0	1.8236832074074072	1	0	0
24	ICE_LB_CHPHW_500	500	15	2308.8	0	0.0215	500	0	3	4	0.33	0	1.2218792515151515	1	0	0
25	ICE_LB_CHPHW_750	750	20	2200.298507	0	0.0215	750	0	3	4	0.345	0	1.1604985652173916	1	0	0
26	ICE_LB_CHPHW_1000	1000	20	1911	0	0.0195	1000	0	3	4	0.368	0	1.019384410326087	1	0	0
27	ICE_LB_CHPHW_2500	2500	20	1624.264151	0	0.01625	2500	0	3	4	0.404	0	0.7856755222772277	1	0	0
28	ICE_LB_CHPHW_5000	5000	20	1182.315789	0	0.00875	5000	0	3	4	0.416	0	0.79739815144230763	1	0	0
29	MT_CHPHW_65	65	15	3220	0	0.0145	65	0	3	5	0.238	0	1.5673651470588237	1	0	0
30	MT_CHPHW_200	200	15	3150	0	0.017	200	0	3	5	0.267	0	1.1006810187265916	1	0	0
31	MT_CHPHW_250	250	15	2719	0	0.012	250	0	3	5	0.261	0	1.2043233754789271	1	0	0
32	MT_CHPHW_1000	1000	15	2500	0	0.0125	1000	0	3	5	0.267	0	1.1044376104868912	1	0	0
33	CT_CHPHW_3500	3500	20	3072.366828	0	0.012	3500	0	3	2	0.2396	0	1.944385523372287	1	0	0
34	CT_CHPHW_5000	5000	20	1945.49588	0	0.0105	5000	0	3	2	0.2891	0	1.466280712556209	1	0	0
35	CT_CHPHW_7500	7500	20	1877.457286	0	0.0101	7500	0	3	2	0.2734	0	1.6297215435259693	1	0	0

Figure 21: DER Technologies Info

After setting the parameters of the discrete technologies we go over to continuous technologies. In our case study we will focus specifically on stationary batteries, heat storage, PV and air source heat pumps. This is done by allowing each of these technologies to be freely selected by DER-CAM, since “ForcedInvest”, and “ForcedCapacity” are set to 0. All technologies not considered in this group are disabled by forcing the capacity to be 0: “ForcedInvest” is set to 1, and “ForcedCapacity” is set to 0 (Figure 22).

Forced Investment Parameters					
	F1	FixedInvest	ForcedInvestCapacity	ExistingYN	Age
1	ElectricStorage	0	0	0	0
2	HeatStorage	0	0	0	0
3	ColdStorage	1	0	0	0
4	FlowBatteryEnergy	1	0	0	0
5	FlowBatteryPower	1	0	0	0
6	AbsChiller	1	0	0	0
7	AbsRefrigeration	1	0	0	0
8	PV	0	0	0	0
9	SolarThermal	1	0	0	0
10	EVs1	1	0	0	0
11	AirSourceHeatPump	0	0	0	0
12	GroundSourceHeatPump	1	0	0	0


Figure 22: Forced Investment parameters for continuous technologies

The Investment Parameters considered for each type of continuous technology used are presented in the Figure 23. Again, we are using default values for the economic characteristics of each technology, but they can be customized freely at any time.

Continuous Investment Parameters					
	F1	FixedCost	VariableCost	Lifetime	FixedMaintenance
1	ElectricStorage	0	193	5	0
2	HeatStorage	0	100	17	0
3	ColdStorage	0	100	17	0
4	FlowBatteryEnergy	0	180	10	0
5	FlowBatteryPower	0	0	10	0
6	AbsChiller	0	685	20	1.88
7	AbsRefrigeration	0	753.74	20	2.07
8	PV	3851.25	3237	30	0.25
9	SolarThermal	0	500	15	0.5
10	EVs1	100	5	1	0
11	AirSourceHeatPump	0	1121	15	1.32
12	GroundSourceHeatPump	0	3510	20	6.3

Figure 23: Investment Parameters for continuous technologies

At this point we are not considering any energy management options or resiliency issues. Therefore, to perform the investment analysis we simply launch the optimization process.

Once the optimization is completed, in addition to visualizing results through our GUI, you may also choose to e-mail yourself results by clicking on . Please note that macros should be enabled in order for this document to work properly.

The result sheet obtained is shown on Figure 24. On Figure 25, where savings are shown in detail, it can be seen that the total annual energy cost decreased from \$221510 to \$189457, even taking into account the annualized investment cost of new technologies. The operational savings obtained are 55.3%: this has to do with the fact that less electricity is bought from the grid and on-site cheaper generation is used instead. In short, we have increased capital costs by investing in new technologies, but our annual operational expenditures are now lower, and the savings obtained are enough to repay for investments within the boundaries set by all financial constraints. It can also be seen from Figure 25 that CO₂ emissions are lowered by 32.4% in the investment case. This decrease in emissions is mainly due to the green energy generated by the PV panels. Details about the annual electricity balance and the annualized energy cost are shown on

Figure 26. The investment decisions are shown on Figure 27.

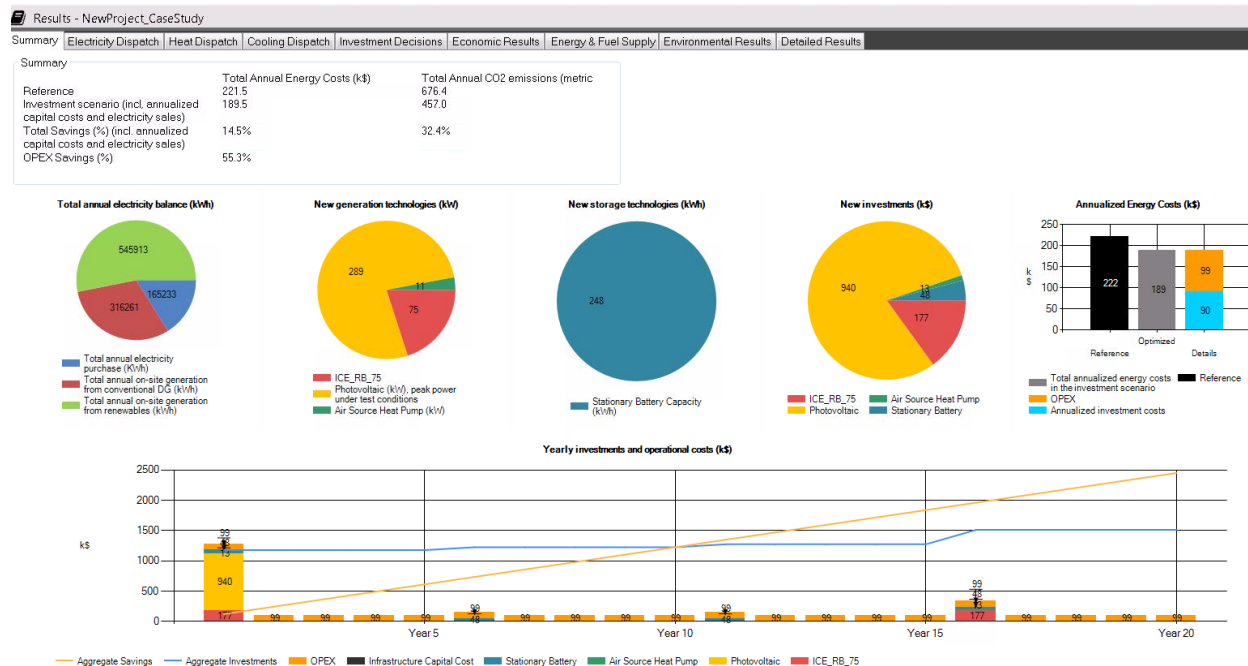


Figure 24: Investment summary section in the result sheet

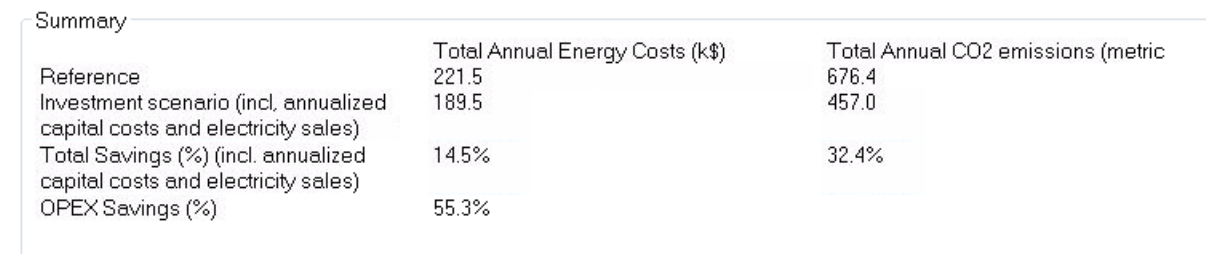


Figure 25: Annual Savings of energy costs and CO2 emissions

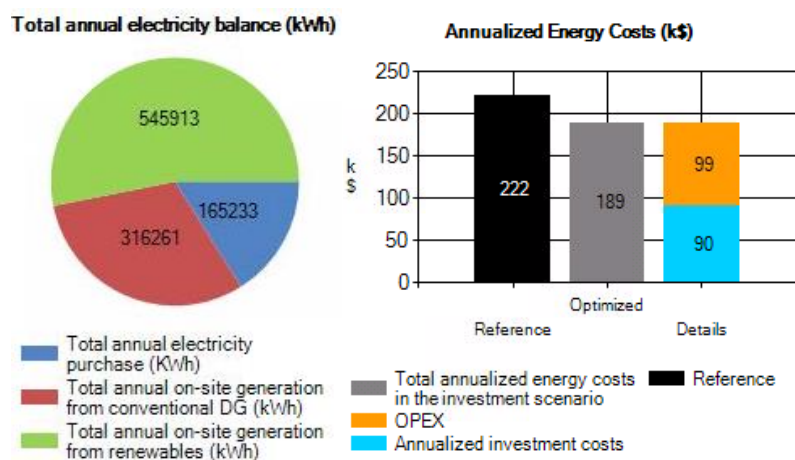


Figure 26: Annual electricity balance and energy costs

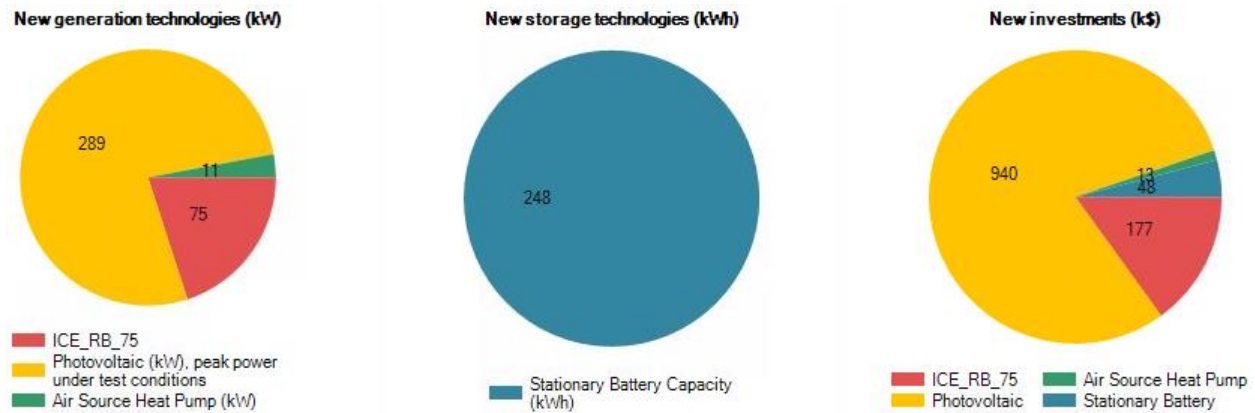


Figure 27: Investments capacities and upfront capital costs

It can be seen that the investment suggested by DER-CAM includes 289kW of PV panels, a 75kW internal combustion engine, an air source heat pump of 11 kW, and an electric storage device with an energy capacity of 248 kWh. No investments in heat storage are suggested. Of all installed technologies the investment in PV is the most capital intensive as shown on the graph on the right side of Figure 27.

Figure 28 shows the dispatch for electricity on a week-day in January. Similar profiles can be found for other day-types during different months and for other end-uses by browsing through the tabs and using the dropdown boxes above the chart. It can be seen that the energy bought from the main grid decreased substantially due to the increase of the PV based self-consumption.

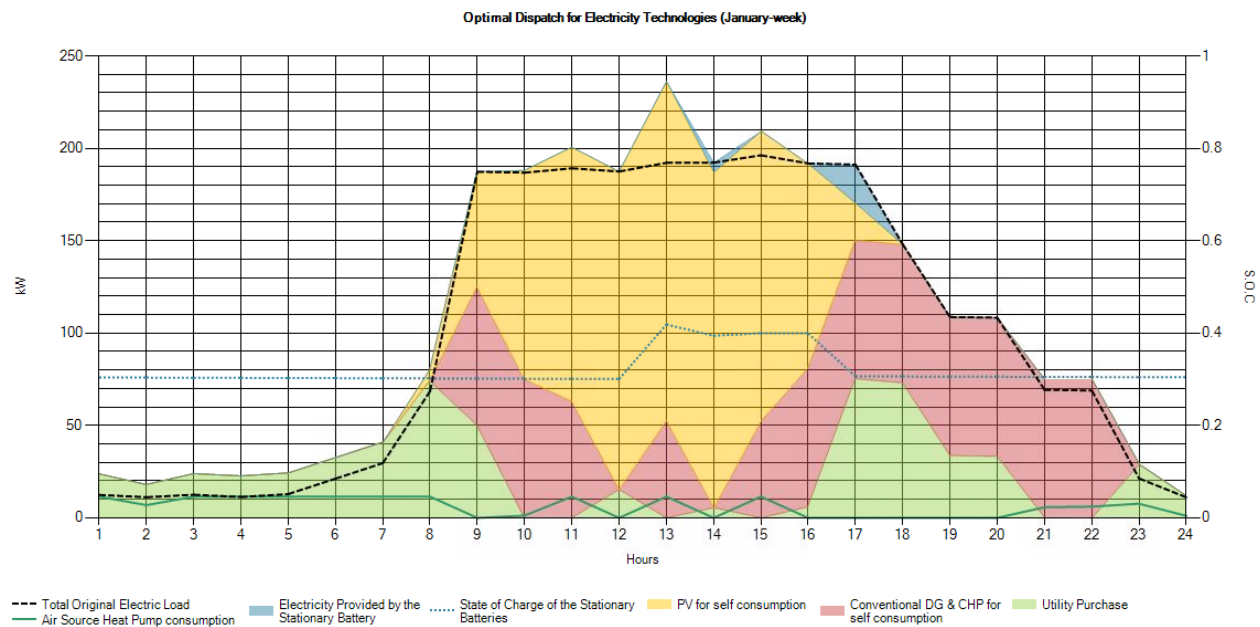


Figure 28: Electricity Dispatch

4. CO2 Minimization

Changing the objective function to CO₂ minimization is simple and it can be done using the “MinimizeCO2” parameter in the Parameter Table of Global Options (Figure 29). Since both the reference costs and investment options have been defined, no other changes are required and the CO₂ minimization run can now be performed.

11	VaryPrice	0
12	CHP	0
13	CO2Tax	0
14	MinimizeCO2	1
15	ZNEB	0
16	MultiObjective	0
17	DiscreteElecStorage	0

Figure 29: Options Table

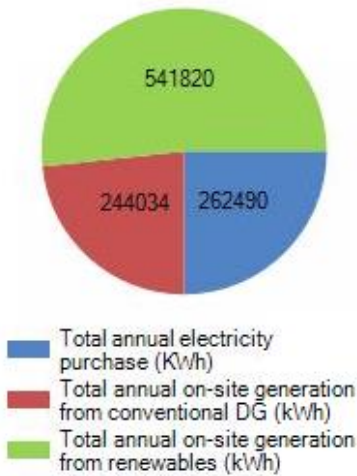
In this case, the results show that the total costs decreased 14.2% in comparison to the reference costs (Figure 30). This value is similar to the cost optimization case (14.5), as in the emissions optimization the financial constraints are still imposed. The annual operational expenses have decreased 55.1%.

In this CO₂ minimization case, the emissions have now decreased by 34.9%, mainly due to the significant reduction of the generation from conventional DG (from 316261 to 244034 kWh), as shown in Figure 31. This occurred mainly due to the changes in the dispatch, since the investments in new technologies remained approximately the same (Figure 32).

Summary		
	Total Annual Energy Costs (k\$)	Total Annual CO2 emissions (metric tons)
Reference	221.5	676.4
Investment scenario (incl. annualized capital costs and electricity sales)	190.0	440.1
Total Savings (%) (incl. annualized capital costs and electricity sales)	14.2%	34.9%
OPEX Savings (%)	55.1%	

Figure 30: Annual savings for costs and CO₂ emissions for the CO₂ (minimization scenario)

Total annual electricity balance (kWh)



Annualized Energy Costs (k\$)

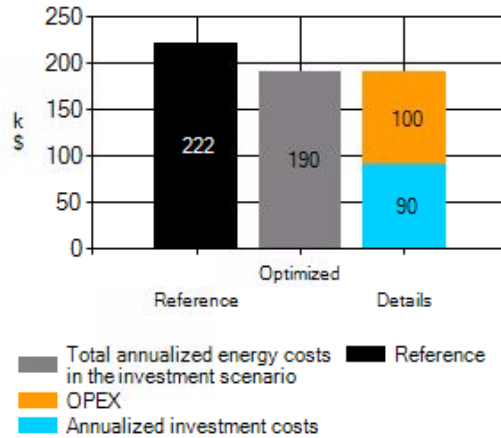
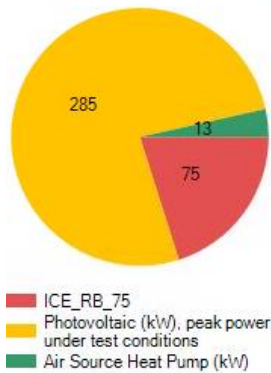
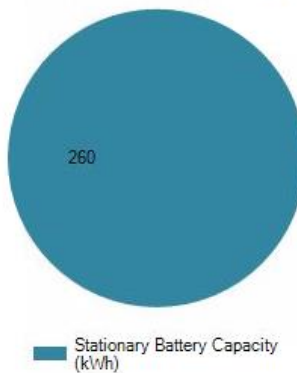


Figure 31: Annual electricity balance and energy costs (minimization scenario)

New generation technologies (kW)



New storage technologies (kWh)



New investments (k\$)

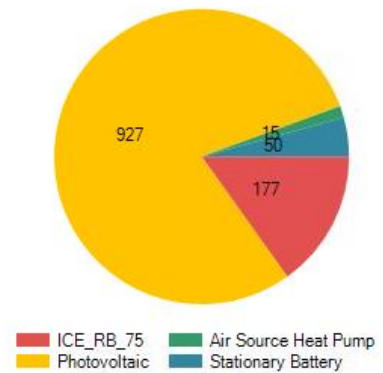


Figure 32: Investments capacities and upfront capital costs for the CO₂ (minimization scenario)

In the CO₂ minimization case DER-CAM suggests an investment of 285 kW in PV, 75 kW in conventional DG and 13kW in air source heat pump. As already mentioned, these values are similar to those presented in the minimization cost scenario. However there was an increase of 12 kWh in the investment in stationary battery. In fact, this small increase in the investment allowed a more intensive use of the electric storage in the dispatch. For example, by comparing the electricity dispatch of Figure 33 with the one presented in Figure 28 , it is possible to observe a more significant use of the energy storage. In particular, the storage is used to increase the purchases from the grid during the night (when the marginal CO₂ emission rates are lower) and deliver it during the day (when the marginal the marginal CO₂ emission rates are higher).

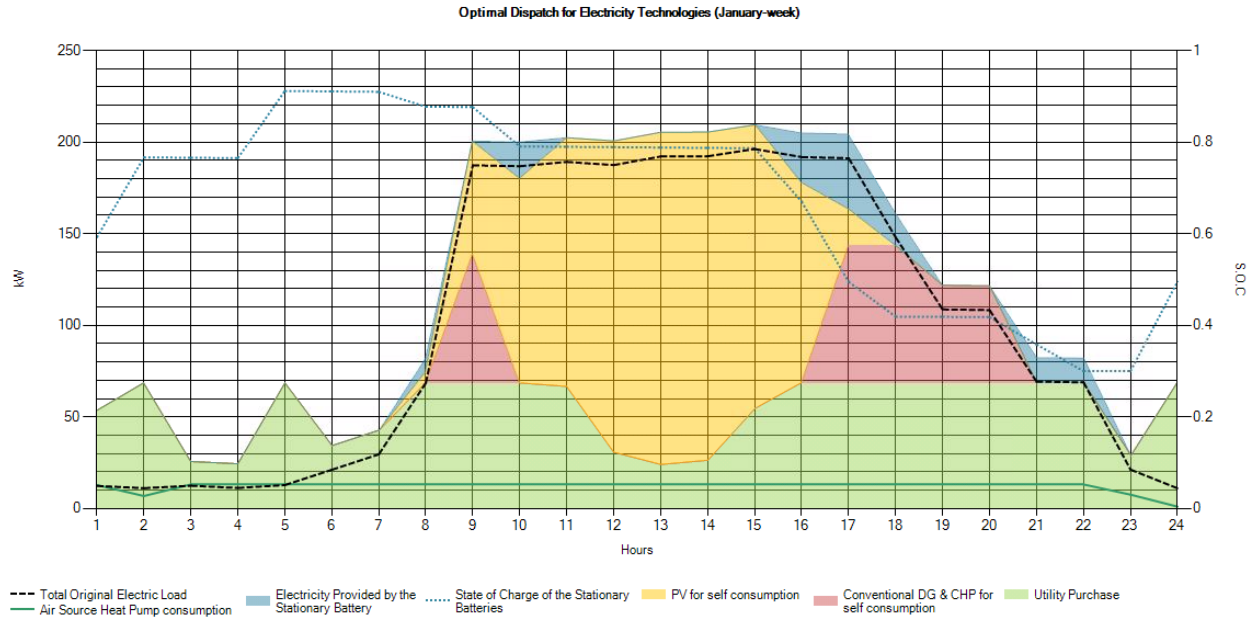


Figure 33: Electricity dispatch for the CO₂ minimization scenario

5. Multiobjective optimization

As previously described, three reference runs must be performed prior to conducting multi-objective optimizations. These are the reference case, the cost minimization case and CO₂ minimization case. Performing these runs allows setting the scaling factors for the cost and CO₂ objectives, “MultiObjectiveMaxCosts” and “MultiObjectiveMaxCO₂”. These values are obtained by finding the costs of a CO₂ minimization run, and the CO₂ emissions of a cost minimization run, respectively.

In our case study we have already obtained all of the necessary information given the runs performed above, and for this reason we only need to update the scaling factors in the Parameters Table found in the Global Settings segment.

Once this information has been introduced, we may now choose how each of the cost and CO₂ objectives must be weighted, by setting the “MultiObjectiveWCosts” and “MultiObjectiveWCO₂”, as shown in Figure 34 . These reflect the relative preference of the user over the criteria.

Changing the goal to a multi-objective approach is done with the Options Table, by setting “MultiObjective” to 1.

	F1	F2
1	IntRate	0.05
2	Standby	0
3	Contrct	0
4	turnvar	0
5	CO2Tax	0
6	macroeff	0.34
7	cooleff	0
8	BaseCaseCost	221510
9	BaseCaseCO2	676367
10	MaxPaybackPeriod	10
11	FractionBaseLoad	0.5
12	FractionPeakLoad	0.1
13	ReliabilityDER	0.9
14	MaxSpaceAvailablePVSolar	9999999
15	PeakPVEfficiency	0.1529
16	MultiObjectiveMaxCosts	189953
17	MultiObjectiveMaxCO2	457045
18	MultiObjectiveWCosts	0.5
19	MultiObjectiveWCO2	0.5
20	ZNEBsolarAreaMultiplier	9.999
21	ZNEBCostsMultiplier	9.999
22	BldgShellLifetime	99
23	MinAnnDERGen	0
24	MinAnnRENGen	0
25	MaxAnnDERGen	9.99
26	EpsilonBaseCaseCost	-9999999
27	EpsilonMaxCO2	-9999999
28	EpsilonMaxPayBack	-99

Figure 34: Parameters table for multi-objective run


The button  allows the user to choose some specific settings of the multiobjective optimization. For example, it is possible to select the number of points to be included in the Pareto frontier as well as the solver precision. Moreover, it is also possible to relax the financial constraints of the problem, by letting cost and Payback period to increase, in order to widen the limits of the multiobjective frontier. In our case study, we will allow a 10% increase of the costs in comparison with the base case (see Figure 35) so that lower CO₂ emissions solutions can be found.

Figure 36 presents the multiobjective frontier with 6 points. Besides the cost minimization solution, it was possible to find 4 additional solutions with lower costs than the base case. Due to the relaxation of the financial constraints, it was also possible to find 1 solution leading to a significant decrease the CO₂ emissions.

Generate Multi-Objective Frontier

Number of frontier points to show (between 3 and 15): 6

Solver Precision: 0.15 ?

Relax financial constraints? ☒ ?

Base Cost increase 10%

Payback period increase 0

OK Cancel

Figure 35: Multiobjective frontier options

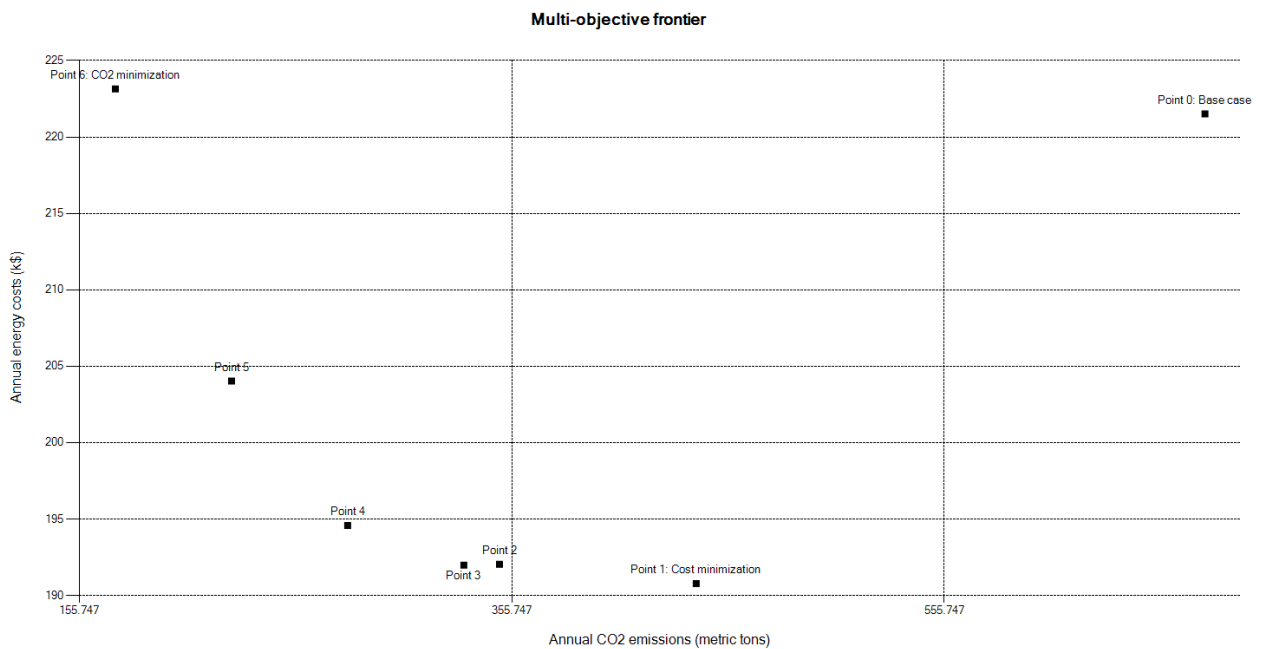


Figure 36: Multiobjective frontier options

6. Cost minimization with existing technologies, forced investments and grid outages

In this section of the case study we assume that 100 kW of PV capacity are already installed on-site although we are willing to consider additional PV. Additionally, we want to force exactly 200 kWh of stationary battery capacity. Finally, in order to test the resilience of the

microgrid, we will simulate an outage from 5 pm to 8.30 pm during a weekday in September.

First of all, because some equipment is pre-installed on-site, we need to run the base case again taking the existing equipment into account. “DiscreteInvest” and “ContinuousInvest” are set to 0 as in the initial reference case because no new investment is allowed, except 100 kW of PV that are now forced in the solution by setting “ForcedCapacity” to 100 and defining it as “Existing”. Figure 37 shows the setting of the continuous technologies Forced Investment Parameters.

Forced Investment Parameters					
	F1	FixedInvest	ForcedInvestCapacity	ExistingYN	Age
1	ElectricStorage	0	0	0	0
2	HeatStorage	1	0	0	0
3	ColdStorage	1	0	0	0
4	FlowBatteryEnergy	1	0	0	0
5	FlowBatteryPower	1	0	0	0
6	AbsChiller	1	0	0	0
7	AbsRefrigeration	1	0	0	0
8	PV	0	100	1	0
9	SolarThermal	1	0	0	0
10	EVs1	1	0	0	0
11	AirSourceHeatPump	1	0	0	0
12	GroundSourceHeatPump	1	0	0	0

Figure 37: Continuous technologies investment constraint

Also, outages costs need to be taken into account in this base case run. To model an outage three steps are required:

- First of all, we set the number of emergency weekdays in September equal to 1 and decrease the amount of ‘normal’ weekdays from 20 to 19 (Figure 38).
- Secondly, we set the hours during which the outage will occur: from 5 pm until 8.30 pm (Figure 39). This can be done in “Electric Utility Availability” table under Resiliency menu.
- Finally, we chose to allow curtailment of electric loads by setting the maximum hours of curtailment higher than 0 for all three priority levels and we assign a variable cost to them. In this case we are not interested in heating load curtailments and leave all the values of those parameters to zero.

It should be noted that the process of valuation of different load curtailments is a very sensitive matter and will have a very significant impact on results. In order to properly assess these numbers it is important to understand all costs that may incur due to loss of

load, including salaries of staff that may be sent home, costs of perishable goods, servers, or any other relevant costs. While some tools may be already available to estimate these costs (e.g. www.icecalculator.com), finding realistic values requires careful analysis and understanding of the site being studied.

Number of Days							
	F1	peak	week	weekend	emergency-week	emergency-peak	emergency-weekend
1	January	1	22	8	0	0	0
2	February	1	19	8	0	0	0
3	March	1	20	10	0	0	0
4	April	1	21	8	0	0	0
5	May	1	22	8	0	0	0
6	June	1	19	10	0	0	0
7	July	1	22	8	0	0	0
8	August	1	21	9	0	0	0
9	September	1	19	9	1	0	0
10	October	1	22	8	0	0	0
11	November	1	20	9	0	0	0
12	December	1	21	9	0	0	0

Figure 38: Number of days

Electric Utility Availability																										
	F1	F2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	January	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	February	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	March	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	April	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	May	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	June	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	July	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	August	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
▶ 9	September	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0.5	1	1	1
10	October	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	November	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	December	emergency-week	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	January	emergency-peak	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 39: Electric utility availability

Curtailment Parameters				
	F1	VariableCost	MaxCurtailment	MaxHours
1	LowCR	3.25	0.2	8760
2	MidCR	26.75	0.7	8760
3	HighCR	50	0.1	8760

Figure 40: Curtailment parameters

The total annual energy costs and total annual CO₂ emissions for the base case are shown on Figure 41 and will be used as reference for the investment runs. The base case cost is

now significantly higher due to the cost of curtailment, especially of mid and high priority load. The electricity dispatch for the emergency weekday in September is shown on Figure 42. It can be seen that curtailment has occurred during the outage.

110	***** Summary *****	
111		
112	Total Annual Energy Costs ...	226784
▶ 113	Total Annual CO2 emission...	571925

Figure 41: Results summary

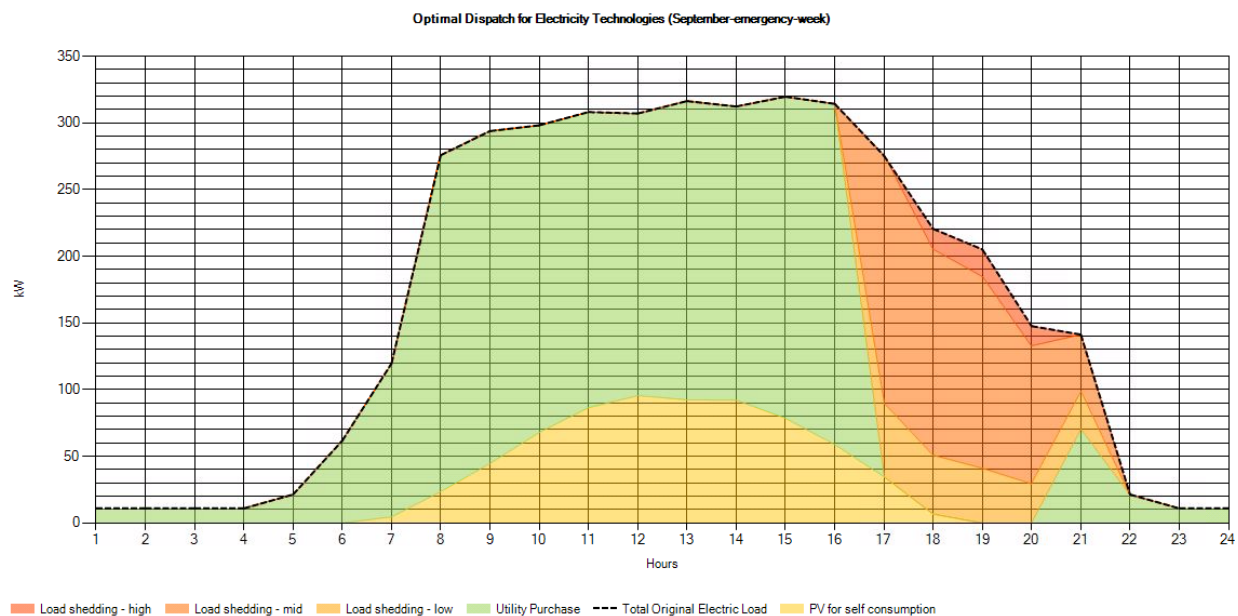


Figure 42: Electricity dispatch for the base case with outage

After obtaining the new reference costs the investment run can be launched. We now allow new investments and set “ContinuousInvest” and “DiscreteInvest” to 1 in the Parameter Table found under Global Settings. In this case we have kept all technology options considered in the initial cost minimization run, but force a stationary battery of exactly 500 kWh. We also allow additional PV investment beyond the pre-existing 100 kW (Fig 41).

Forced Investment Parameters					
	F1	FixedInvest	ForcedInvestCapacity	ExistingYN	Age
1	ElectricStorage	1	500	0	0
2	HeatStorage	0	0	0	0
3	ColdStorage	1	0	0	0
4	FlowBatteryEnergy	1	0	0	0
5	FlowBatteryPower	1	0	0	0
6	AbsChiller	1	0	0	0
7	AbsRefrigeration	1	0	0	0
8	PV	0	100	1	0
9	SolarThermal	1	0	0	0
10	EVs1	1	0	0	0
11	AirSourceHeatPump	0	0	0	0
12	GroundSourceHeatPump	1	0	0	0

Figure 43: Continuous technologies constraints

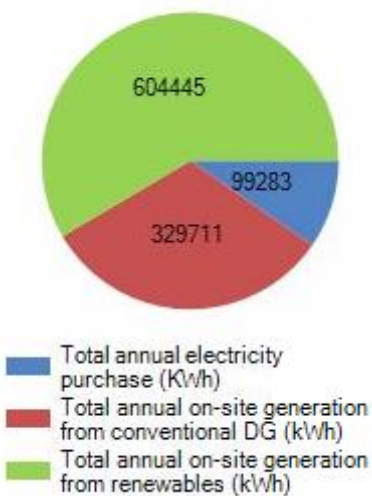
The obtained results are shown by Figure 44. Total annual energy costs savings of 15.1% were possible and CO₂ emissions lowered by 23.5% when compared to the reference case. The investment decisions are shown by Figure 46.

Summary

	Total Annual Energy Costs (k\$)	Total Annual CO2 emissions (metric tons)
Reference	226.8	571.9
Investment scenario (incl. annualized capital costs and electricity sales)	192.5	437.2
Total Savings (%) (incl. annualized capital costs and electricity sales)	15.1%	23.5%
OPEX Savings (%)	53.2%	

Figure 44: Annual savings for costs and CO2 emissions for the outage scenario

Total annual electricity balance (kWh)



Annualized Energy Costs (k\$)

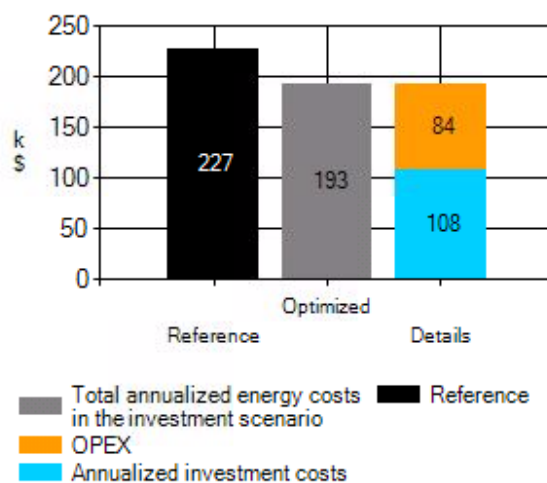


Figure 45: Annual costs and CO2 emissions savings

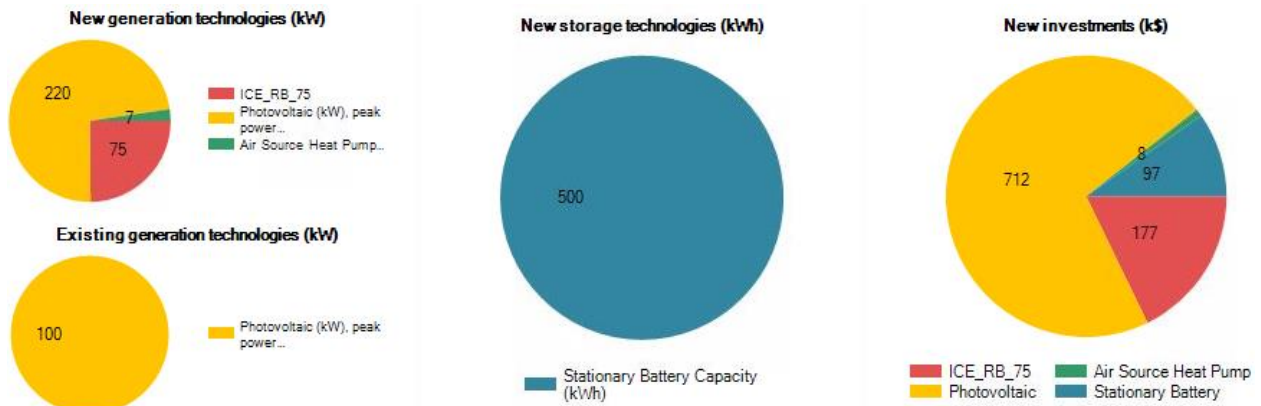


Figure 46: Investments capacities and upfront capital costs

No curtailment occurred as the new investments allow enough on-site generation to prevent them from happening (Figure 47).

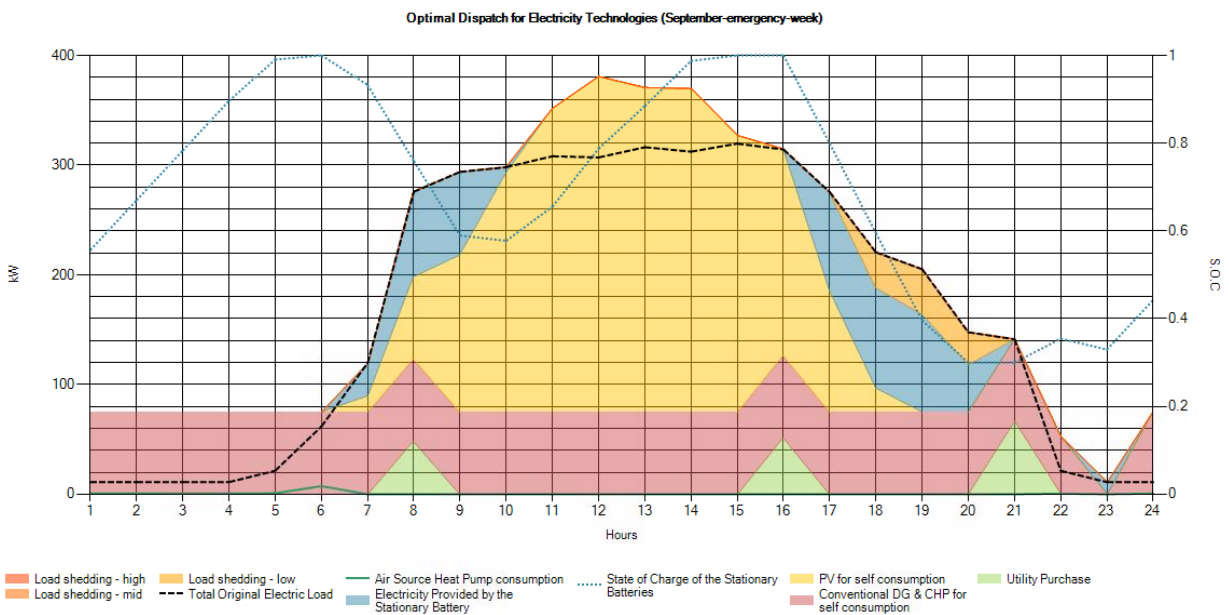


Figure 47: Electricity dispatch with outage

It can be seen that during the outage period the loads are mainly served by the stationary battery. Simultaneously, a significant part of the low priority load is curtailed. It should be noted, however, that given the nature of the optimization algorithm, results are biased by foresight. In other words, as every time steps is solved simultaneously and is equally valued in the solution process, results reflect the anticipation of an outage, which will lead

to an optimistic use of the battery. Although this is a limitation of the current DER-CAM version, it is possible to minimize this effect by applying the battery cycling obtained in standard day-types to the end-use loads and re-adjusting the available battery size.

Annex A: Assessments Levels for DER-CAM use

1. Basic User Level

The Basic Level for DER-CAM is intended primarily for learning purposes or for quick scanning of options at sites where the existing databases (energy loads, solar radiation, and tariffs) are relevant.

This level requires users to pre-select a site by using the load, solar radiation, and tariff databases present in DER-CAM. No entering of custom load, solar, and tariff data is possible.

The menu options available are limited, and the available options are meant to help users solidify the understanding of the workflow of DER-CAM models. As DER-CAM analyses typically require both a reference run and an investment analysis run, these two run types are available. However, run modifiers such as enabling power exports or forcing zero net energy balance are disabled, and the technology options available are also limited and no edits are allowed in any of the pre-defined technology parameters. This includes both economic and performance data. The Basic User Level should enable fast and easy first order microgrid assessment runs.

2. Intermediate User Level

The Intermediate DER-CAM user level includes all of the features available in the basic mode, such as the loads, solar radiation, and tariff databases.

However, greater flexibility and a wider number of features is made available to the user as all of the database inputs (loads, solar radiation, and tariffs) may be customized by users to model more complex situations. Furthermore, the Intermediate User Level allows using of some of the Load Management and Resiliency features, including the definition of outages and load priority levels for load curtailment analysis in islanding conditions. It is equally possible to enable power exports of onsite generation, as well as the definition of feed-in tariffs and power export conditions (minimum and/or maximum requirements).

The Intermediate User Level does not allow changing technology parameters, but enables users to test microgrid conditions including outages (forced islanding) and gauging the tradeoff between outage costs induced by load curtailments and investment costs from additional DERs to serve loads when the utility is unavailable.

3. Advanced User Level

The Advanced DER-CAM user level includes all of the features available in the Intermediate User Level, including the ability to edit energy loads, solar radiation data, as well as tariff information.

In addition, all technology definitions are now unlocked and users are allowed to modify existing data and input custom technologies. Additional load management features are enabled, including load shifting and demand response.

By enabling these features users can not only define real sites, but also express the technical characteristics of DER equipment relevant to a particular manufacturer, rather than using the reference values made available through the DER-CAM template.

The Advanced User Level empowers users with all of the most commonly used DER-CAM features, and will typically allow building a customized microgrid model that fully covers the case under study.

4. Full User Level

The Full User Level of DER-CAM grants users complete access to all input data and parameters that are required to build the most complex models. Energy loads, weather data, tariff information, technology options, and energy management options are all enabled, thus allowing very complex models to be created.

All features available in the Advanced User Level are included in the Full User Level, and additional features are now enabled, namely building shell improvement measures, financial incentives such as investment subsidies and performance based incentives, net metering, and Zero Net Energy constraints. This level requires advanced experience and training in using DER-CAM.

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